The Arctic System Reanalysis: Motivation, Development, and Performance

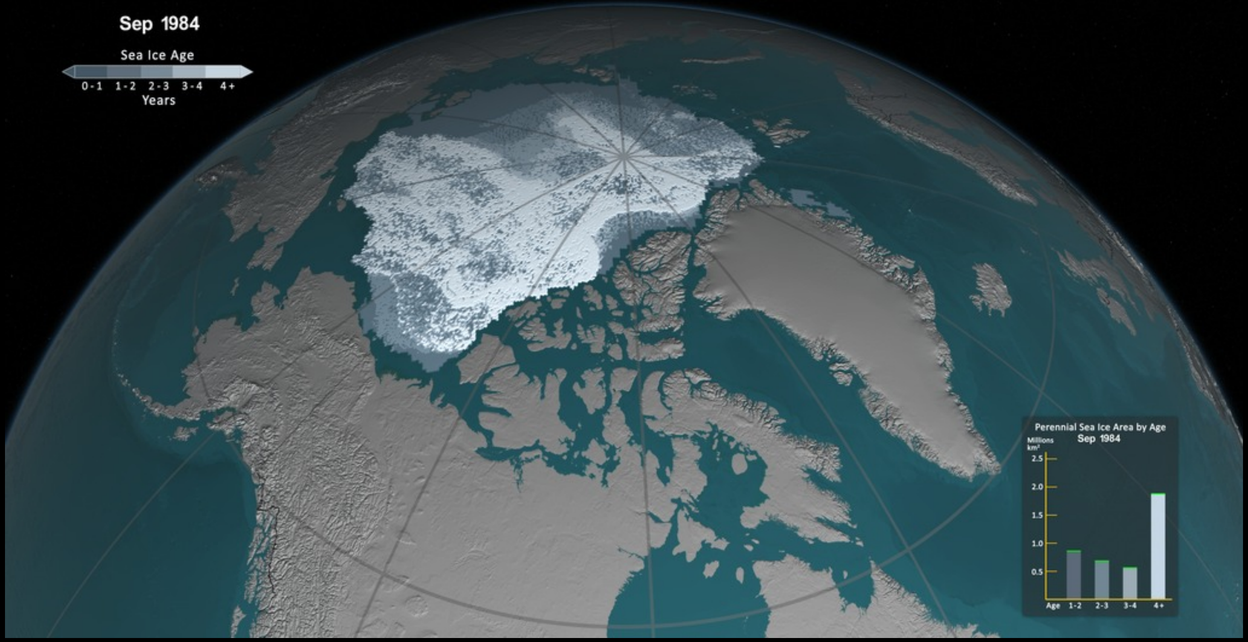
David H. Bromwich

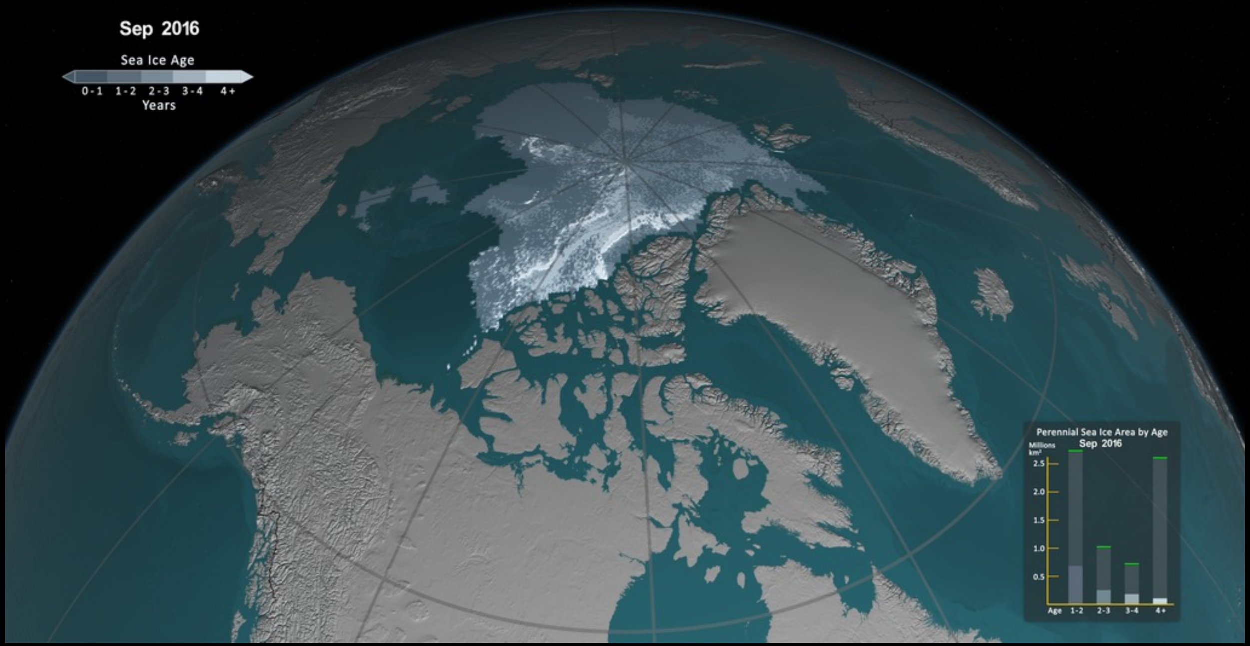
A. B. Wilson, L.-S. Bai, G. W. K. Moore, K. M. Hines, S.-H. Wang, W. Kuo, Z. Liu, H.-C. Lin, T.-K. Wee, M. Barlage, M. C. Serreze, J. E. Walsh, and A. Slater

Outline

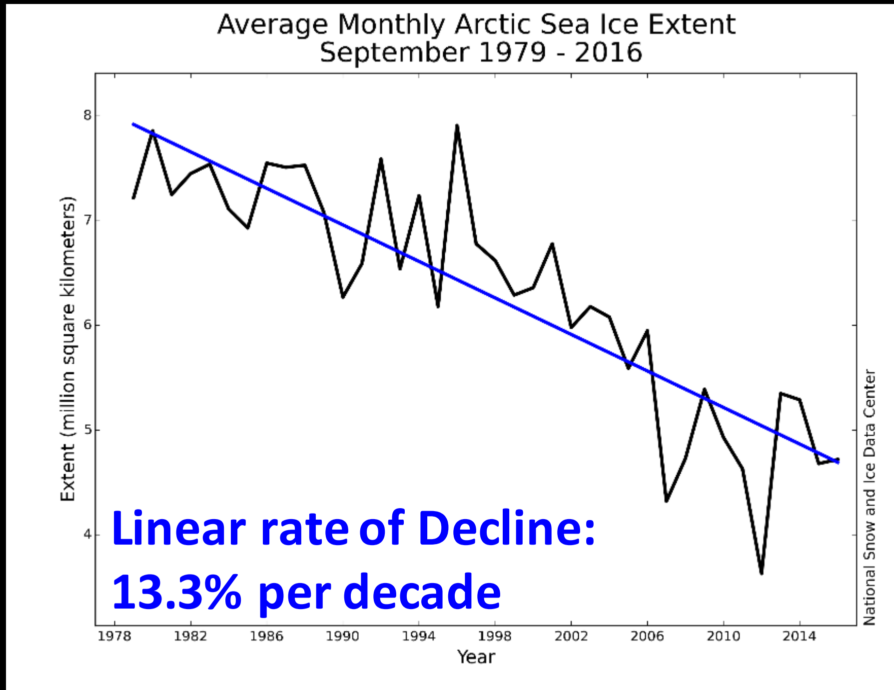
- Arctic Climate Change
- ASR Motivation
- ASR Description
- Comparison with ERA-Interim
- Topographically Forced Winds
- Other Mesoscale Phenomena
- Next Step: ASRv3

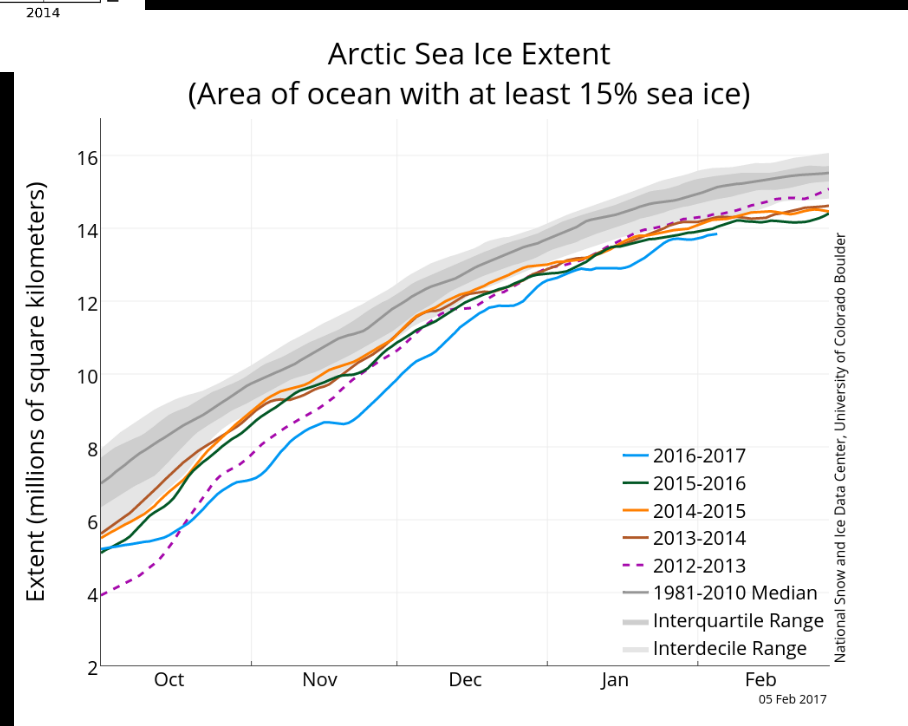
ARCTIC SEA ICE DECLINE





ARCTIC SEA ICE DECLINE





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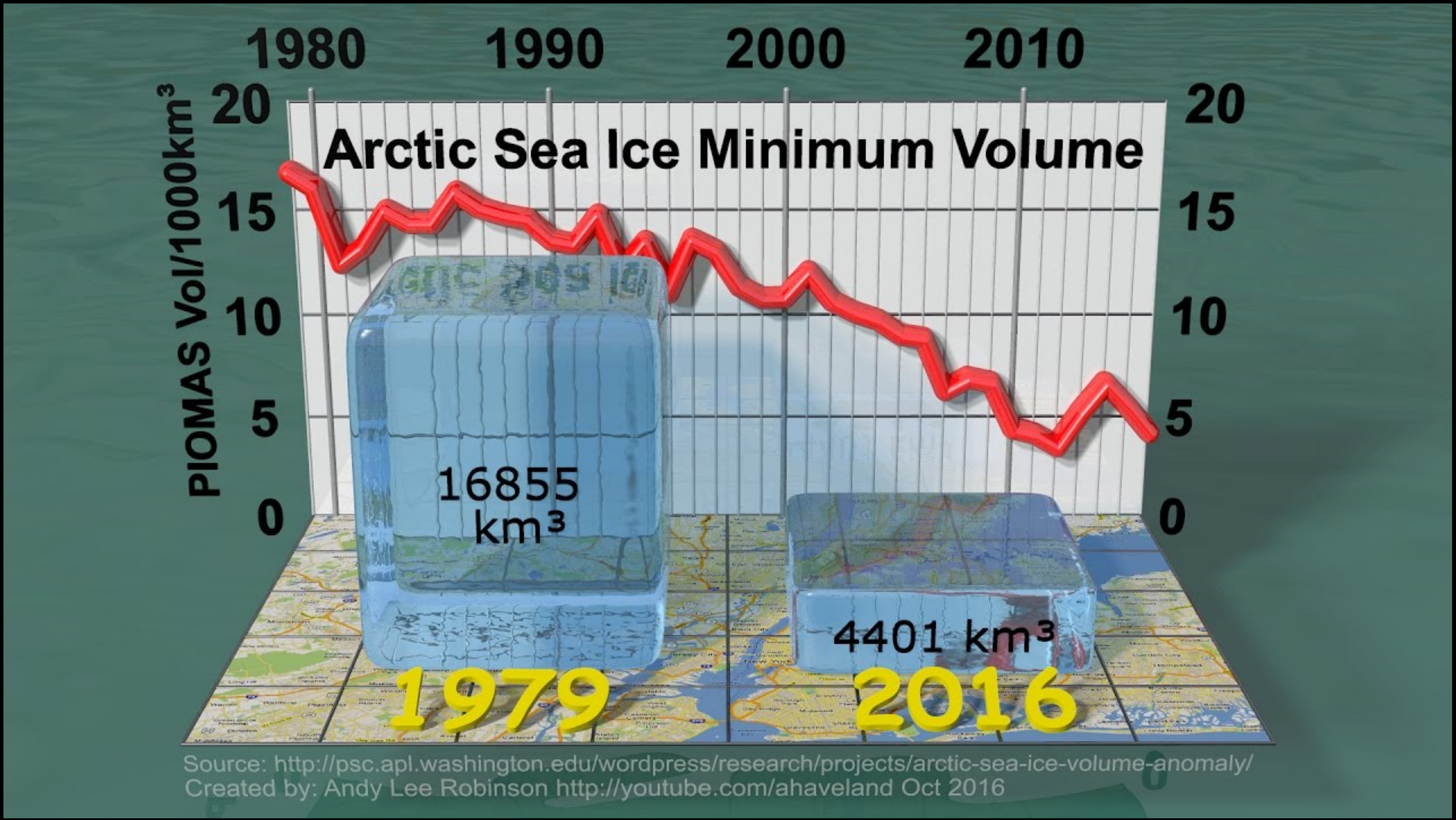
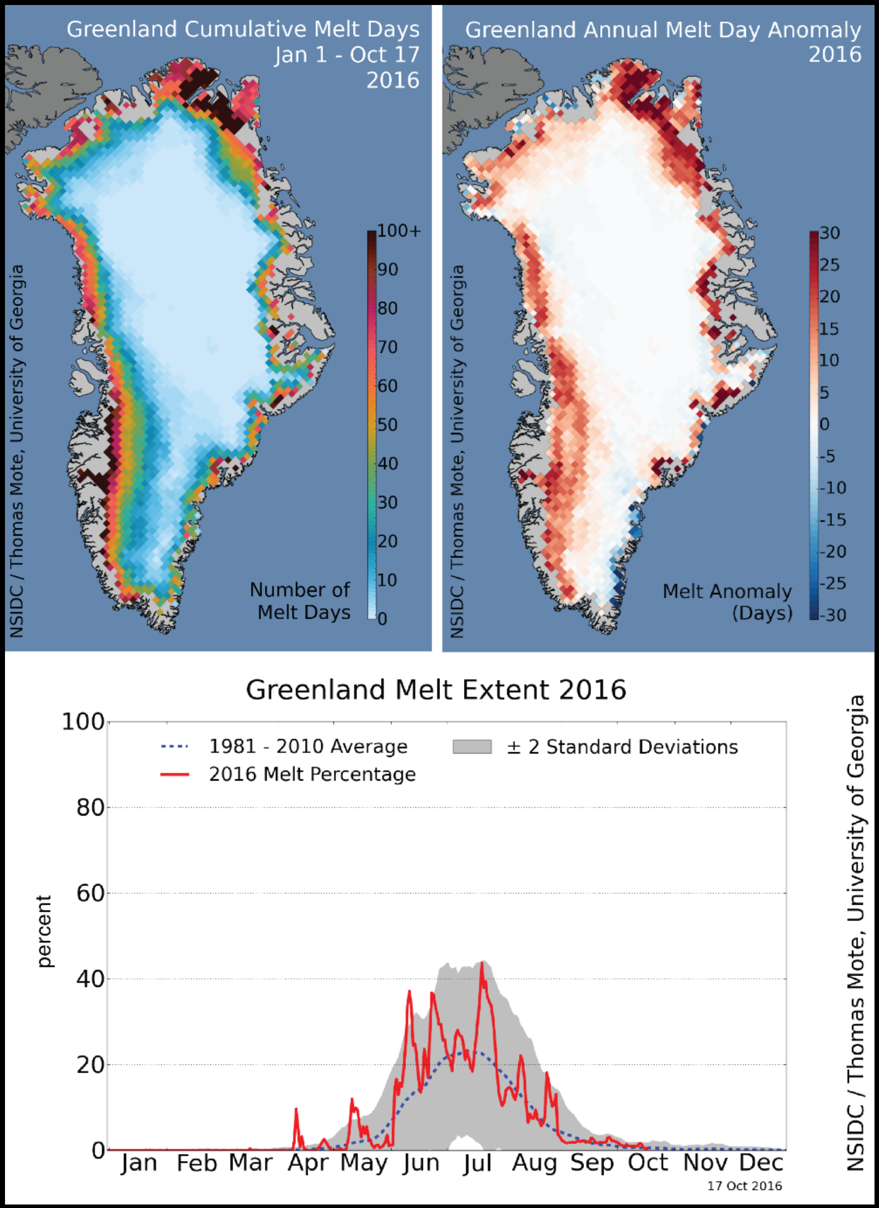
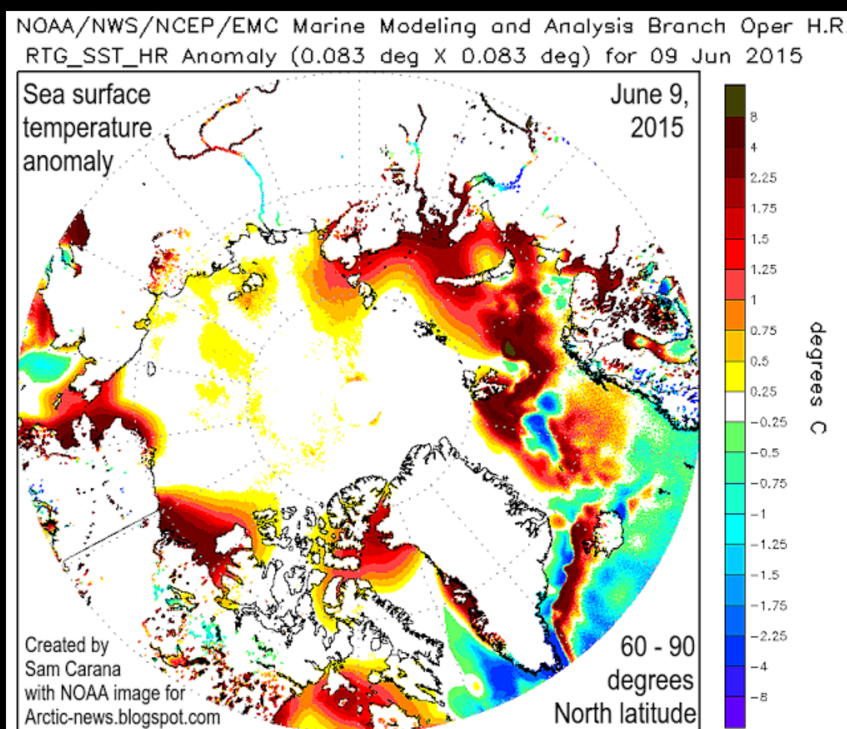


GREENLAND MELT



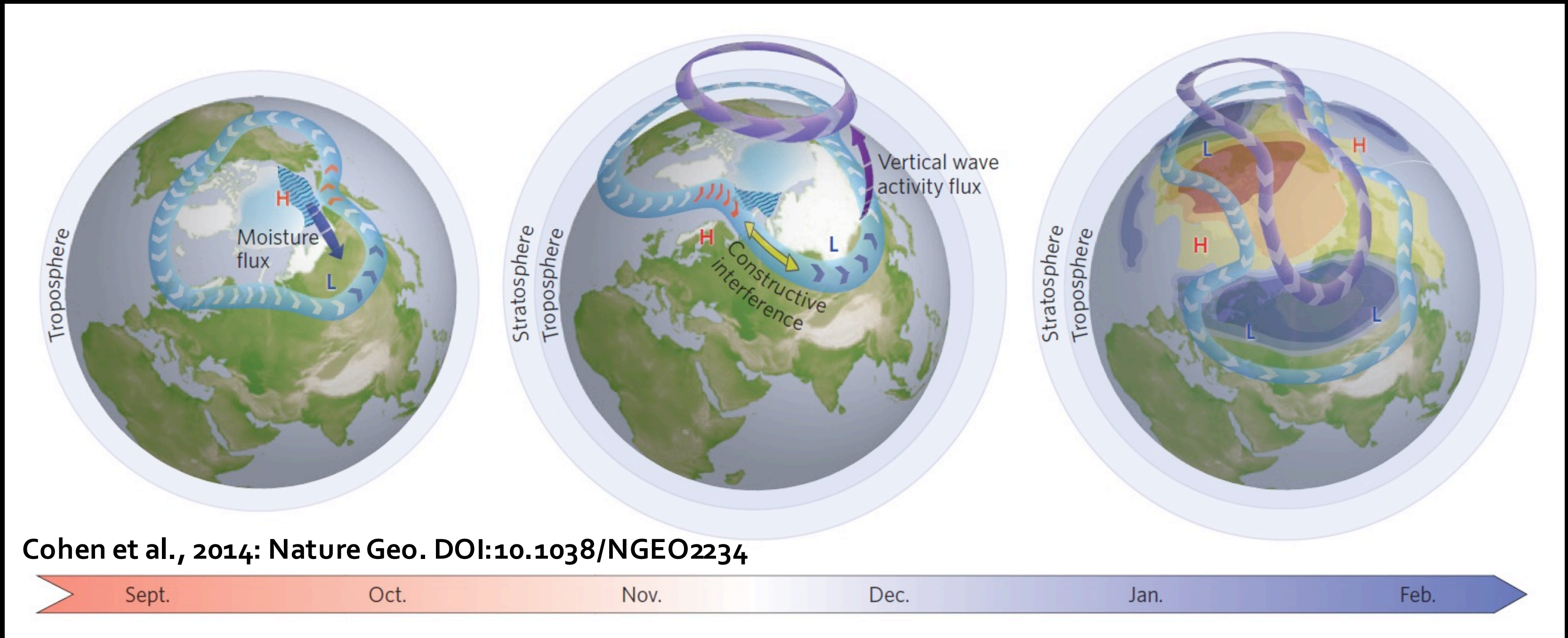
OTHER ARCTIC CHANGES

Using 29 years of data from Landsat satellites, researchers at NASA have found extensive greening in the vegetation across Alaska and Canada. (Cindy Starr / NASA's Goddard Space Flight Center)

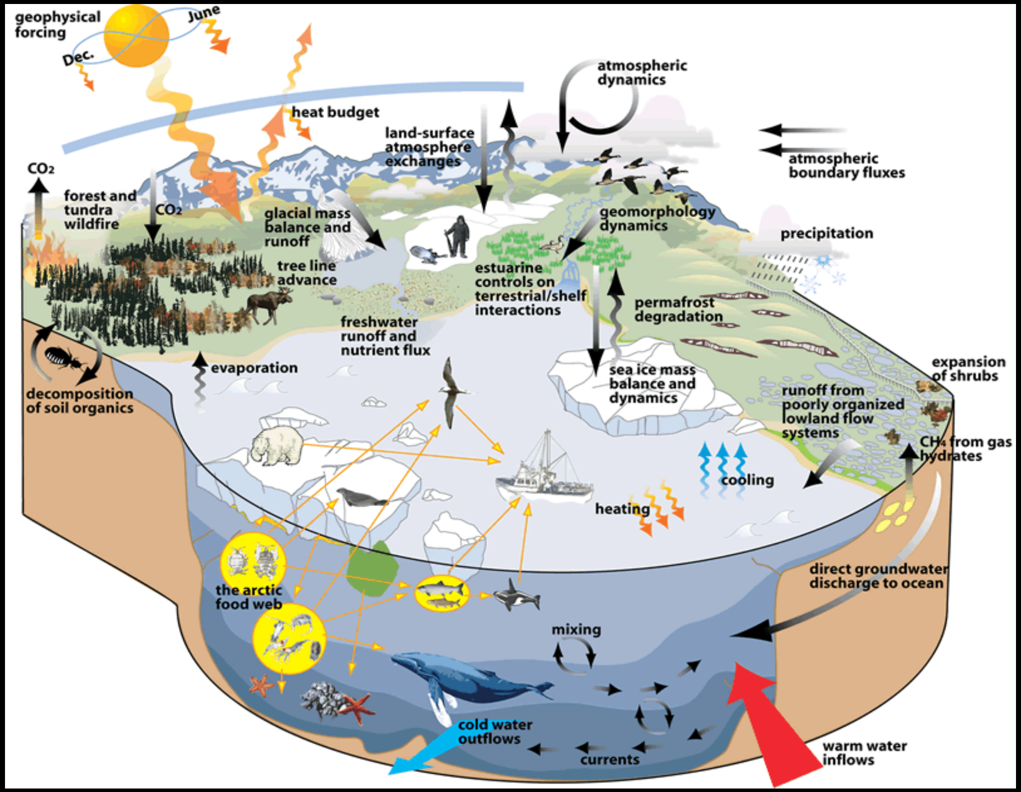


Irina Overeem stands on the rapidly eroding coastline near Drew Point, northern Alaska. Photo by Robert Anderson. https://instaar.colorado.edu

MID-LATITUDES IMPACTS



- Sea-ice loss in the Chukchi and East Siberian seas and an Increase in Eurasian snow cover impact mid-tropospheric geopotential heights
- Increase vertical propagation of Rossby waves from the troposphere into the stratosphere; Weakens the polar vortex; ridging over the Arctic
- Warmer conditions prevail in the Arctic regions
- Colder and more severe winter weather occurs across the mid-latitude continents of the Northern Hemisphere; also persistent ridging



Arctic Climate System

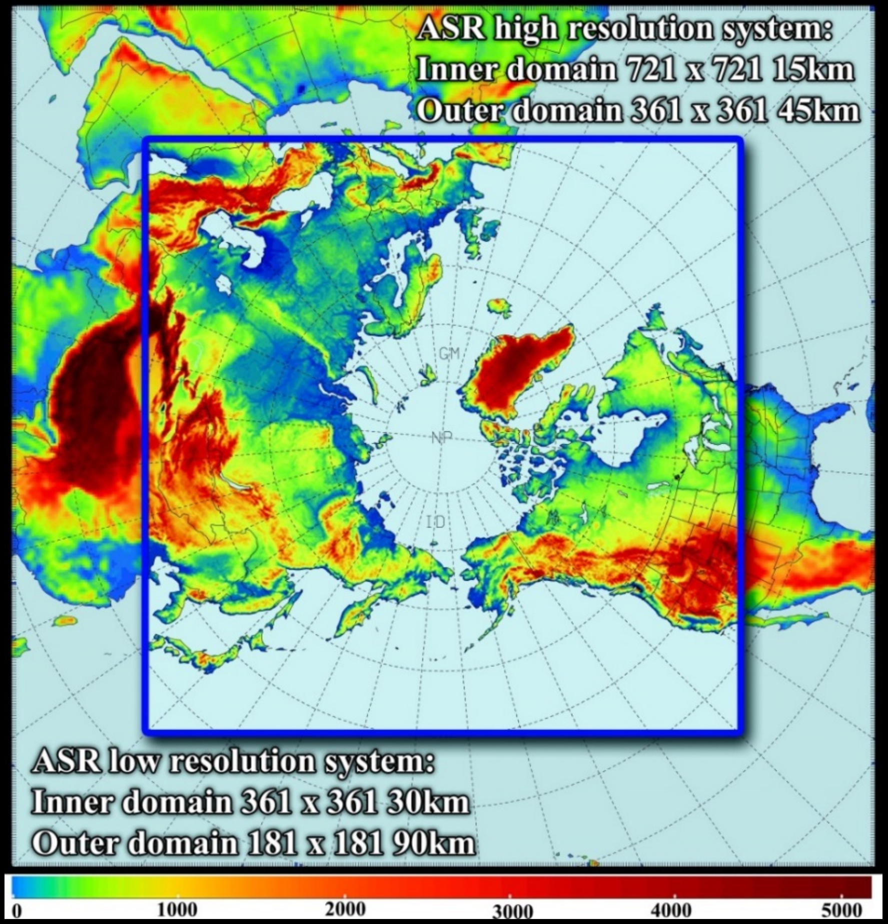
- ***Complex Interactions***
- ***Rapidly Changing***
- ***Amplified*** warming with multiple feedbacks

What is needed?

- ***Comprehensive*** picture of the changing Arctic climate
- Improved ***temporal and spatial resolution*** over existing global reanalyses
- ***A system-oriented approach*** focusing on the atmosphere, land surface and sea ice

Arctic System Reanalysis

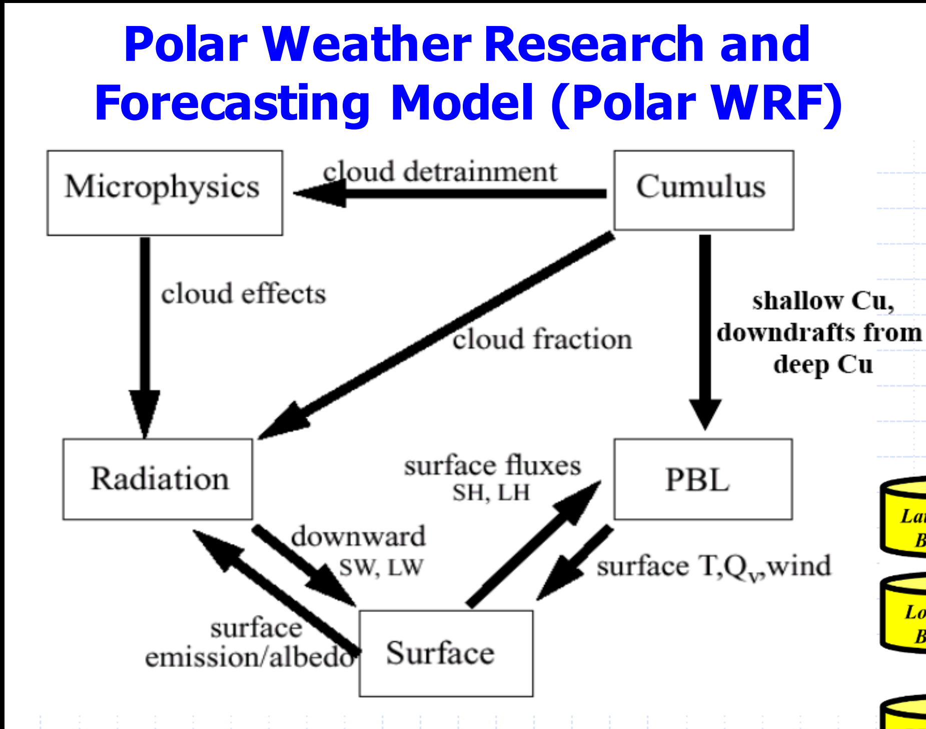
- Regional reanalysis of the Greater Arctic (2000-2012)
  - Includes major Arctic rivers and NH storm tracks
- Uses Polar WRF with WRFDA (3D-VAR)
- Two Versions
  - ASRv1-30km & ASRv2-15 km
  - 71 Vertical Levels (1st level – 4m)
  - 3h output

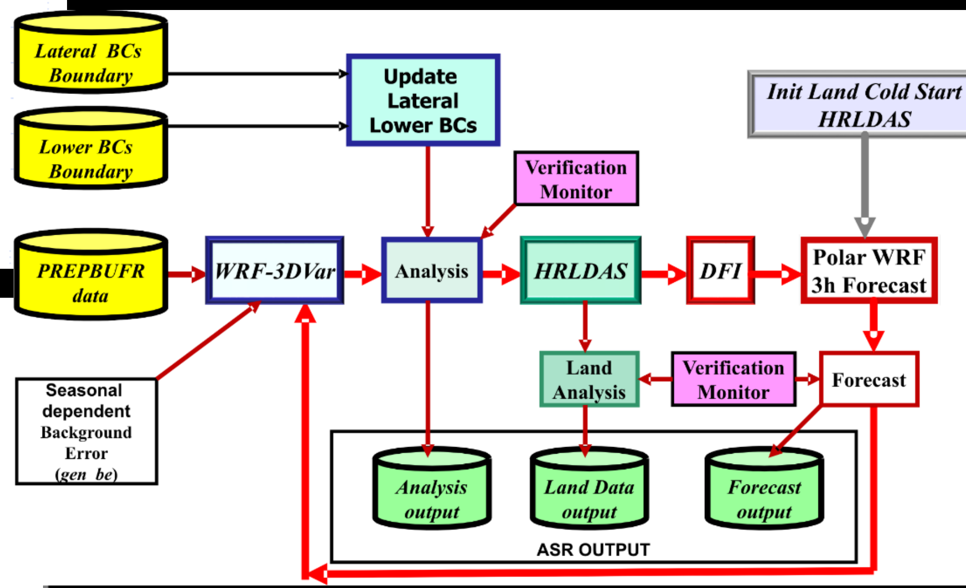


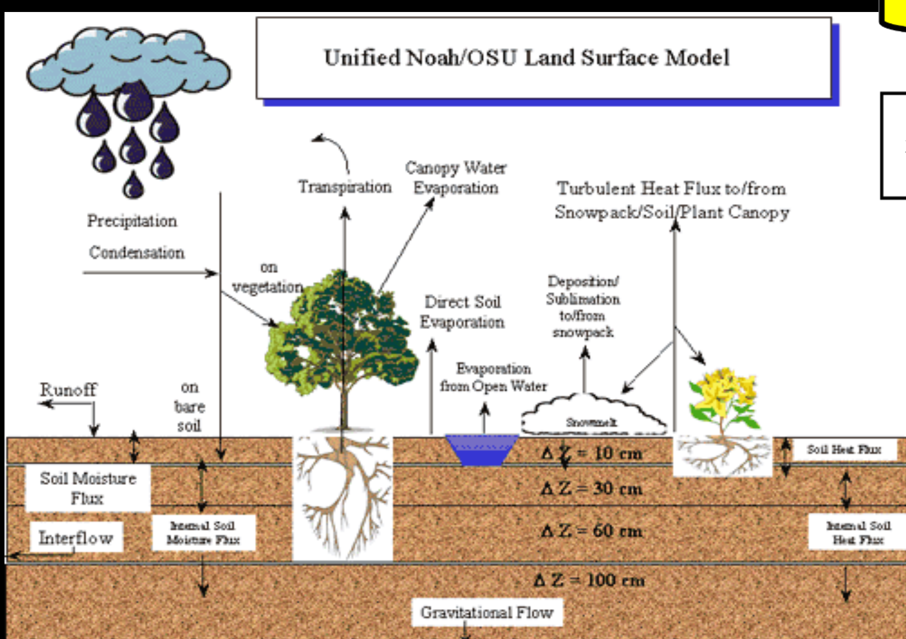
ASRv1: Bromwich et al. 2016 QJRMS
ASRv2: Bromwich et al. 2017 BAMS (in prep)

ASRv1 30 km and ASRv2 15 km available online at the NCAR CISL Research Data Archive

ASR Components







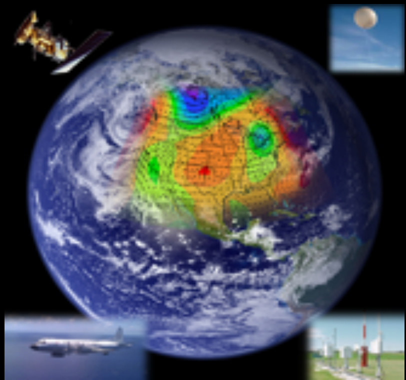
Polar WRF (versions 3.1-3.8.1)

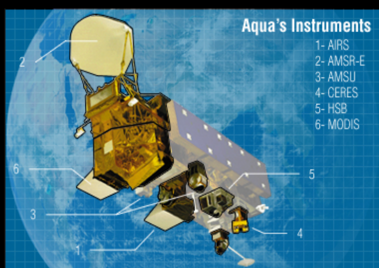
- Improved treatment of heat transfer for ice sheets and revised surface energy balance calculation in the Noah LSM

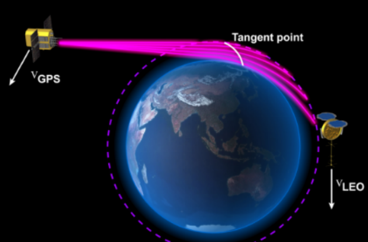
- Comprehensive sea ice description in the Noah LSM including:
  - Sea ice fraction specification (mosaic method) – works with MYNN surface boundary layer
  - Specified variable sea ice thickness (ASR-inspired)
  - Specified variable snow depth on sea ice (ASR-inspired)
  - Sea ice albedo seasonal specifications (ASR-inspired)

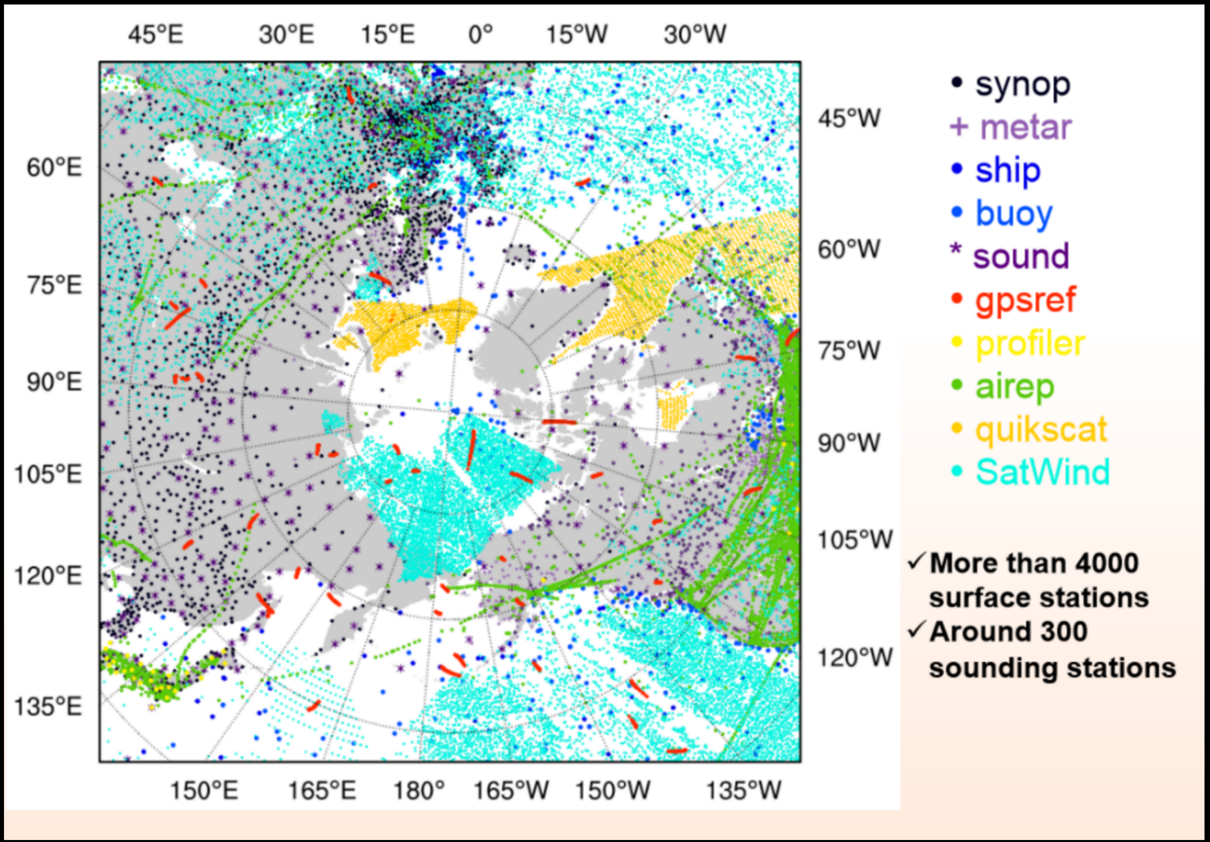
- Improved cloud microphysics for polar regions – ongoing

Atmospheric Data Assimilation in ASR with WRFDA (3D-Var)









Snapshot of Available Data on December 1, 2007 within a 3hr window

OSC Resource Utilization for ASRv2 (15 km)

ASR High Resolution Data Assimilation with 3hr Cycling Mode Based on 2048 Cores (15km, 71 layers)

Run Time	CPU (wall clock)/RU	Storage (TB)		
13 years (2048 cores)	ASR data assimilation (Polar WRF WRFDA HRLDAS)	Model level	Pressure level	Observation data
	120 days	100	60	30
	120 days	190 TB		

December 2006 – November 2007 (3 h comparison)

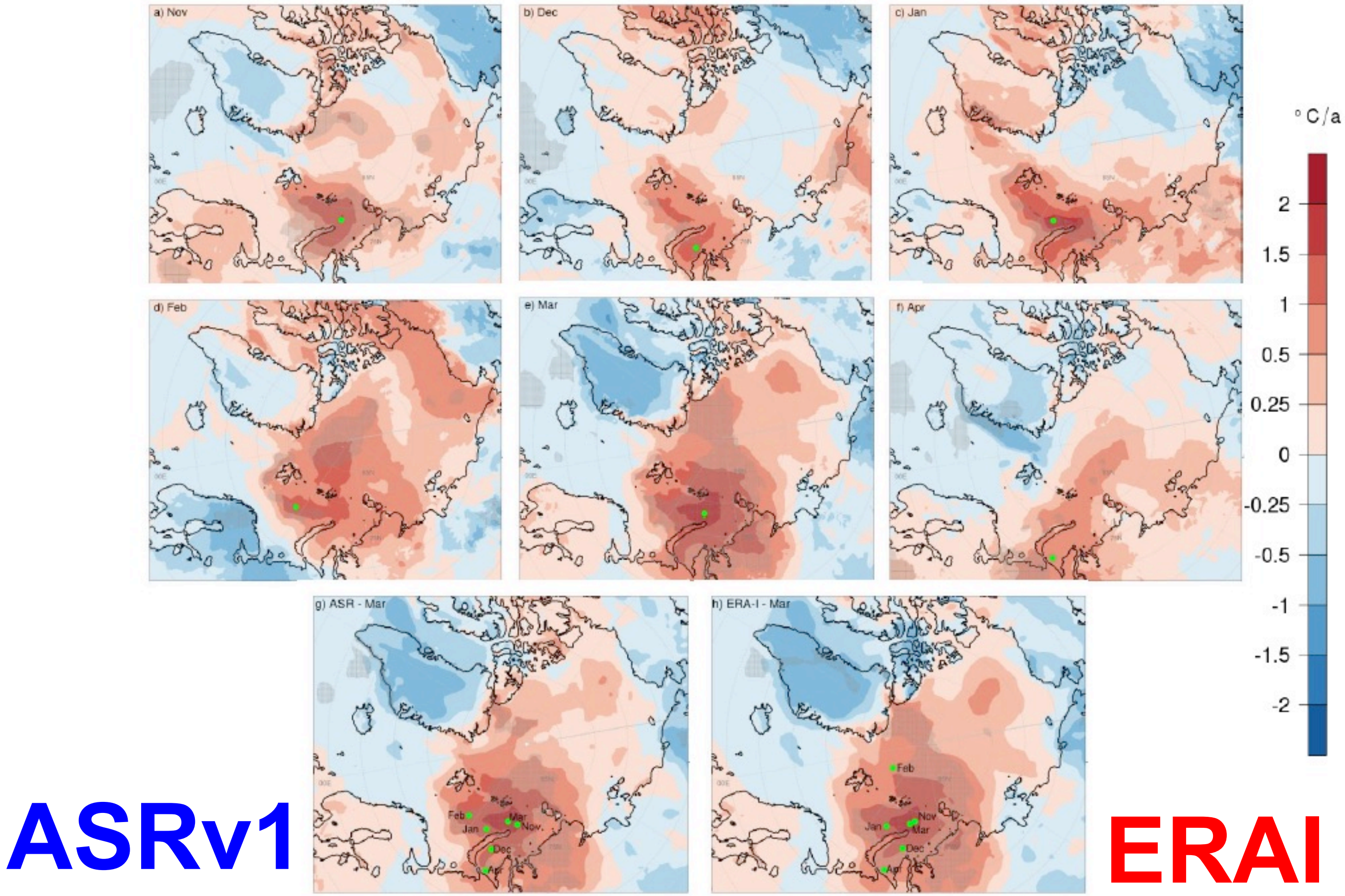
Surface

Name	2 m Temperature (°C)			2 m Dewpoint (°C)		
	Bias	RMSE	Correlation	Bias	RMSE	Correlation
ERAI	0.29	1.99	0.92	0.32	2.04	0.88
ASRv1	0.10	1.33	0.96	-0.02	1.72	0.92
ASRv2	-0.04	1.08	0.97	0.22	1.51	0.94

Over 4000 stns.	Surface Pressure (hPa)			10 m Wind Speed (m s^{-1})		
	Bias	RMSE	Correlation	Bias	RMSE	Correlation
ERAI	-0.03	0.98	0.99	0.41	2.13	0.64
ASRv1	0.03	0.83	0.99	-0.24	1.78	0.70
ASRv2	-0.03	0.70	0.99	0.24	1.40	0.80

- Very small 2 m temperature and dewpoint biases in ASRv2 with much improved RMSE over ERAI
- Large scale synoptic patterns well captured – great match with ERA; very high skill in surface pressure
- Small 10 m wind speed biases – 20% more variance captured by ASRv2 than ERAI

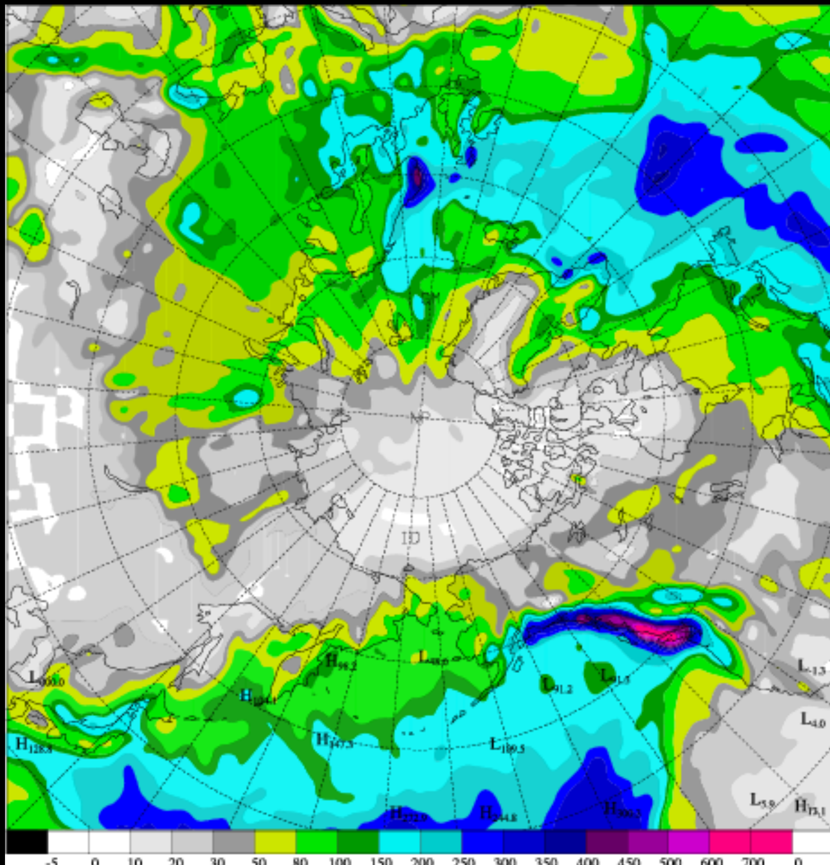
ASR and Air Temperature Trends

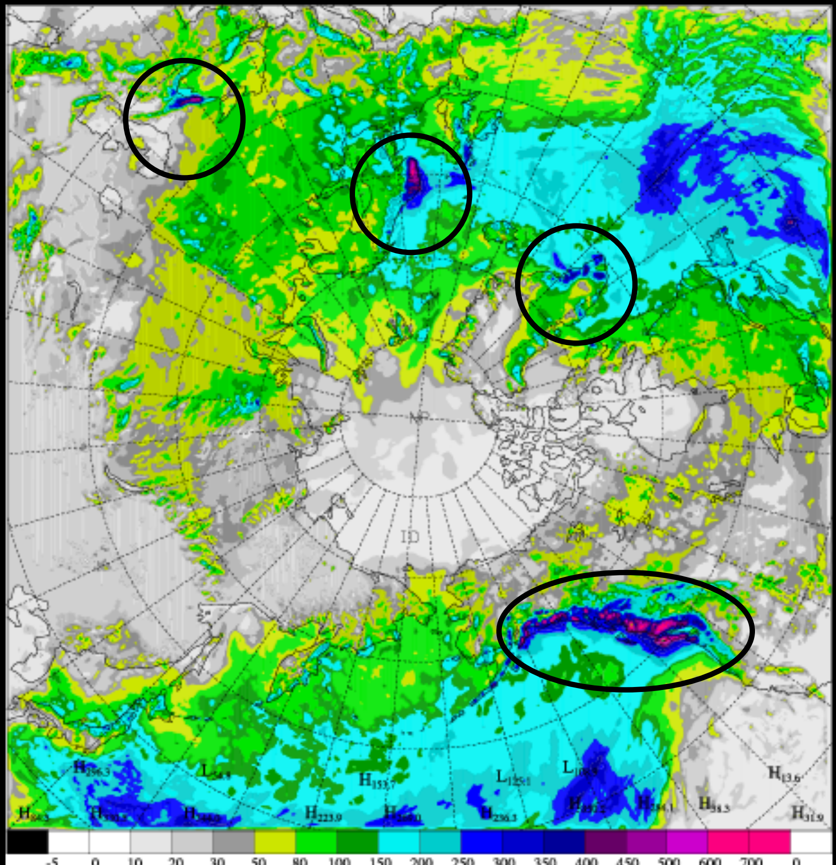


Kohnemann et al., 2017: *J. Climate*, accepted.

FIG. 6. Spatial trends of the 2-m air temperature for CCLM monthly mean winter months for 2002 to 2012 (a-f). Gray shaded regions indicate 95% significance. Spatial trends of ASR (g) and ERA-I (h) for Marches 2002 to 2012. The green dots show the region of the maximum trend for the individual months.

Precipitation

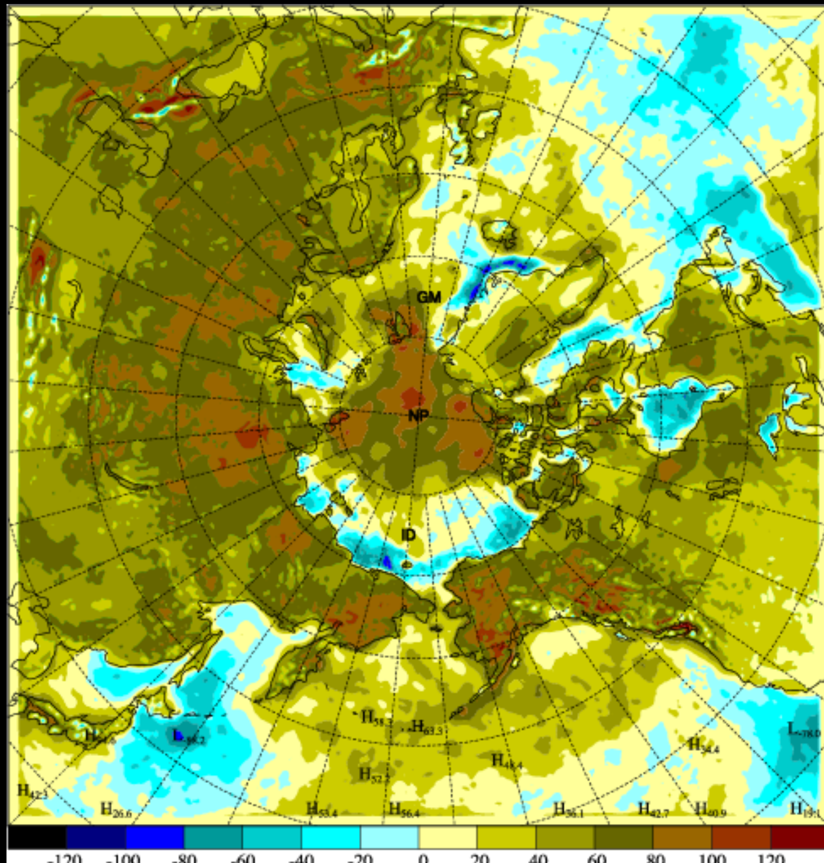


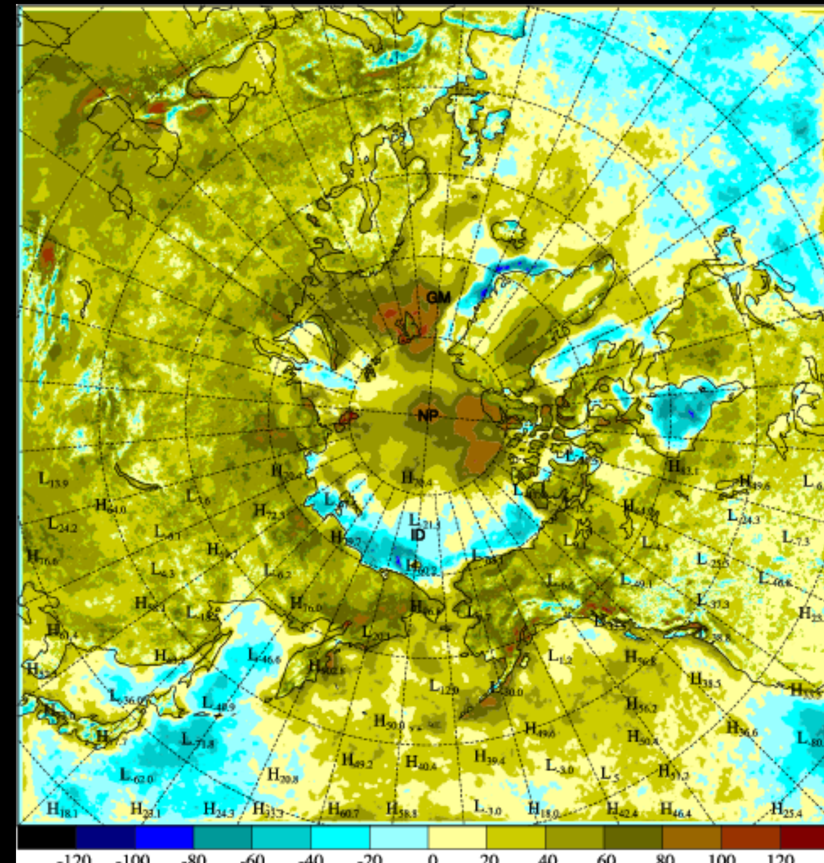


ERAI **January 2007** ASRv2

Precipitation	Midlatitudes (299 stns)			Polar (75 stns)		
% Bias	ERAI	ASRv1	ASRv2	ERAI	ASRv1	ASRv2
Annual (Dec 06-Nov 07)	-2.7	2.0	-4.9	-2.5	-7.8	-6.4
Cold (Sep-Feb)	-4.3	-6.2	-12.5	-1.5	-3.2	-6.5
Warm (Mar-Aug)	-3.0	9.5	1.2	-0.9	-10.5	-4.5

Incident Shortwave

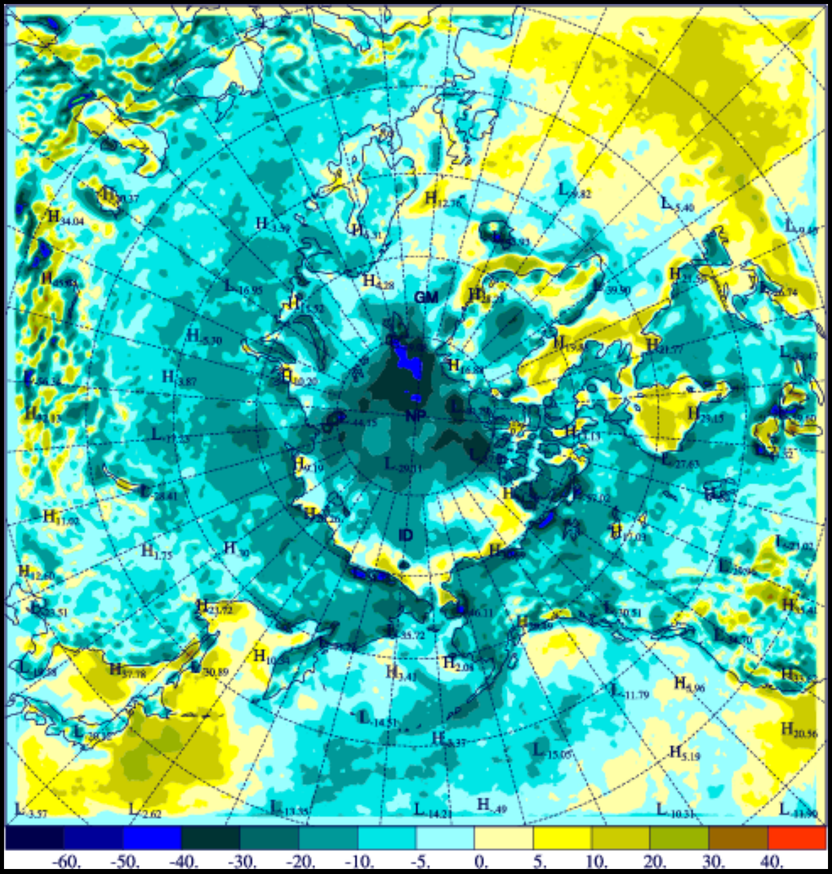


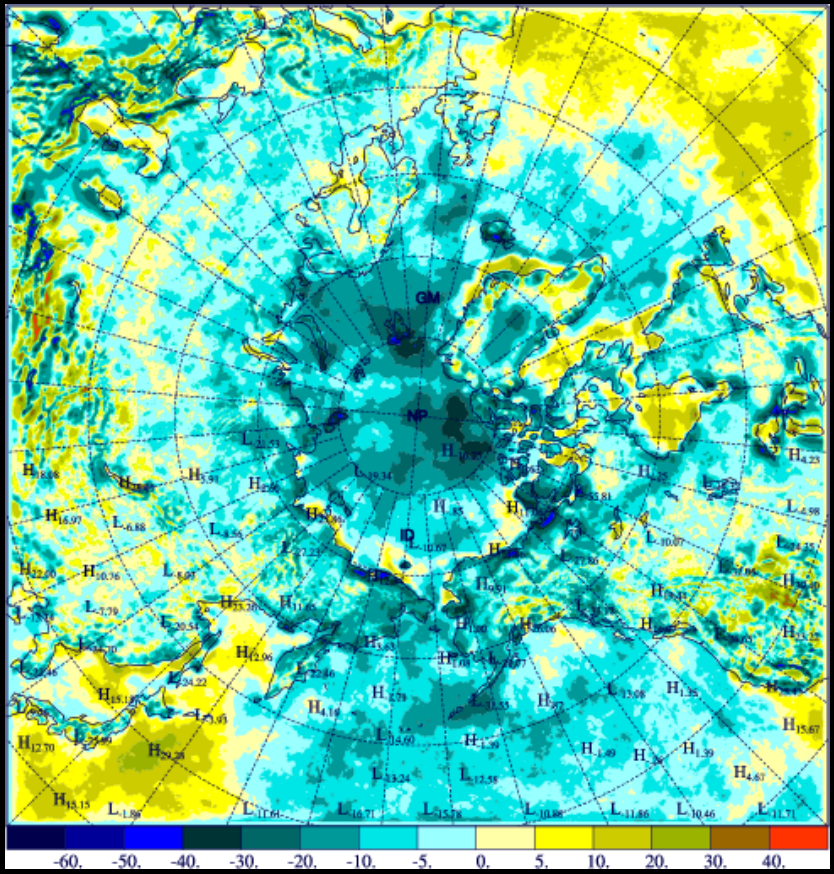


ASRv1-ERAI **June 2007** **ASRv2-ERAI**

Incident SW vs BSRN	Midlatitudes (5 stns)			Polar (6 stns)		
Annual (Dec 06-Nov 07)	ERAI	ASRv1	ASRv2	ERAI	ASRv1	ASRv2
Bias (W m^{-2})	14.6	42.0	27.0	-6.7	17.6	14.8
RMSE	118.8	104.6	95.3	55.6	53.8	55.4
Correlation	0.83	0.92	0.92	0.82	0.87	0.86

Downwelling Longwave

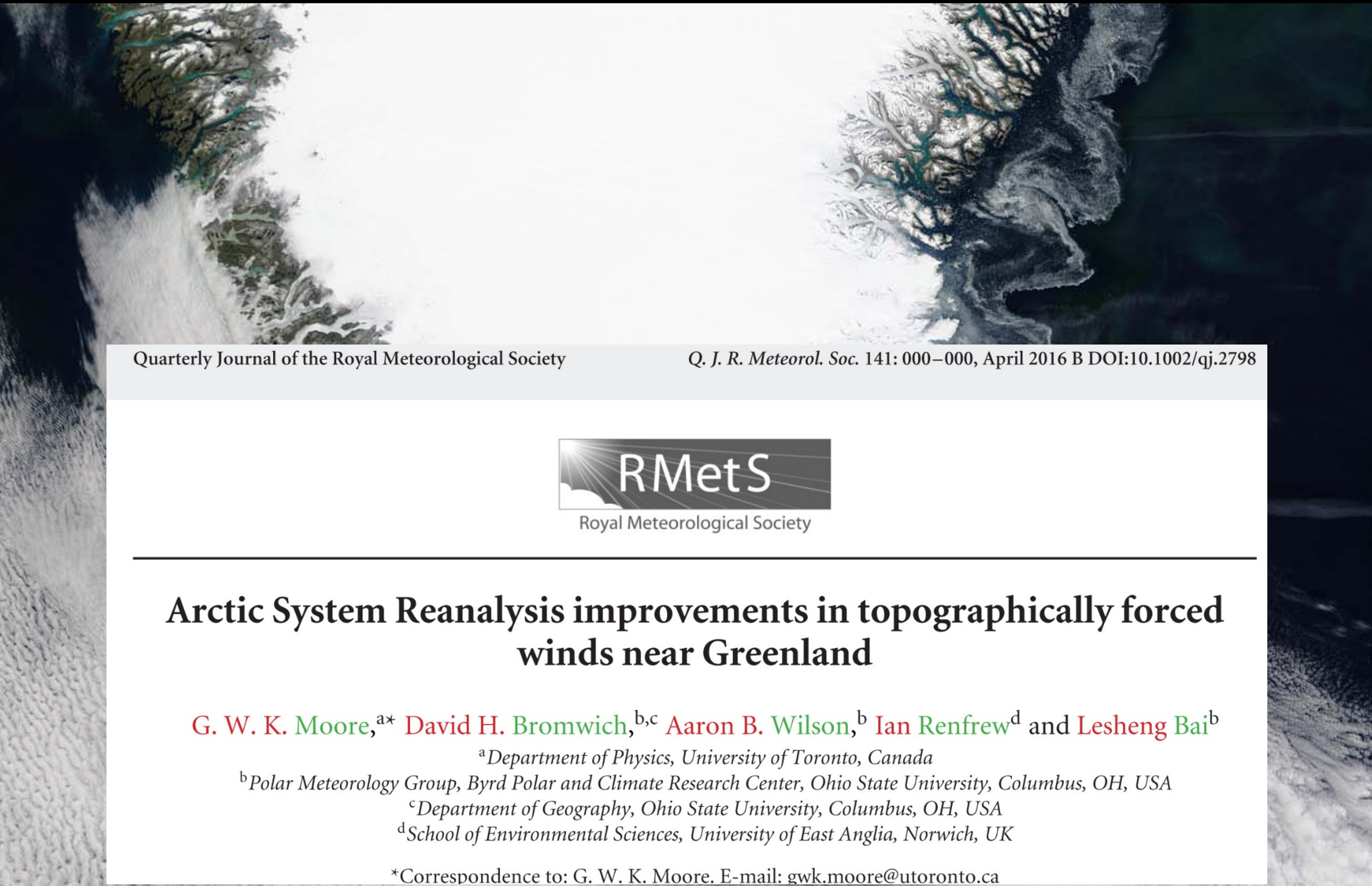




ASRv1-ERAI **June 2007** **ASRv2-ERAI**

Downwelling LW vs BSRN	Midlatitudes (5 stns)			Polar (6 stns)		
Annual (Dec 06-Nov 07)	ERAI	ASRv1	ASRv2	ERAI	ASRv1	ASRv2
Bias (W m^{-2})	-8.8	-11.4	-6.8	-5.9	-11.8	-13.9
RMSE	23.5	26.3	24.9	27.8	34.0	34.6
Correlation	0.80	0.77	0.78	0.66	0.59	0.61

Topographically-Forced Winds



Quarterly Journal of the Royal Meteorological Society Q. J. R. Meteorol. Soc. 141: 000–000, April 2016 B DOI:10.1002/qj.2798

RMetS
Royal Meteorological Society

Arctic System Reanalysis improvements in topographically forced winds near Greenland

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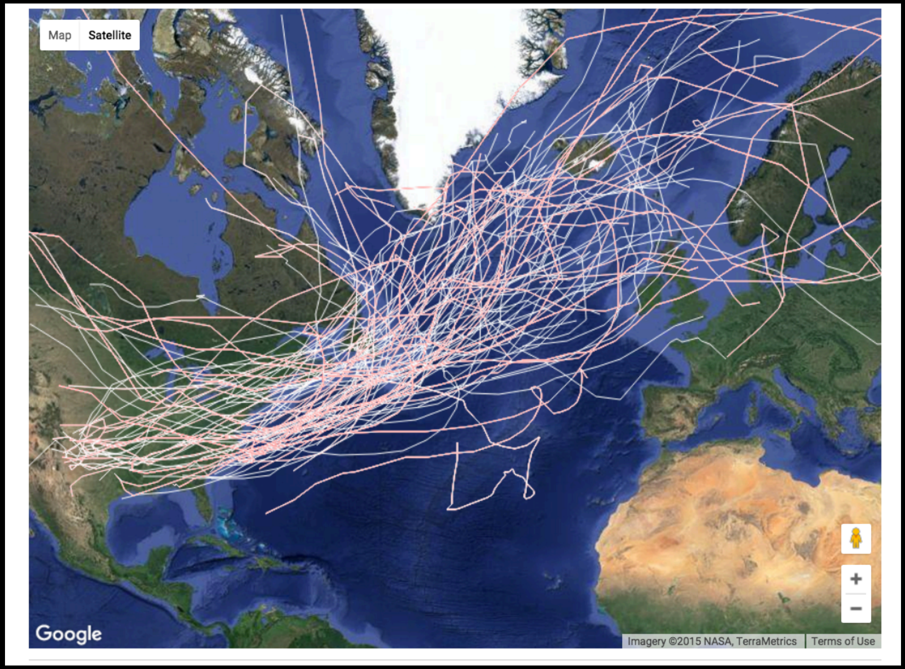
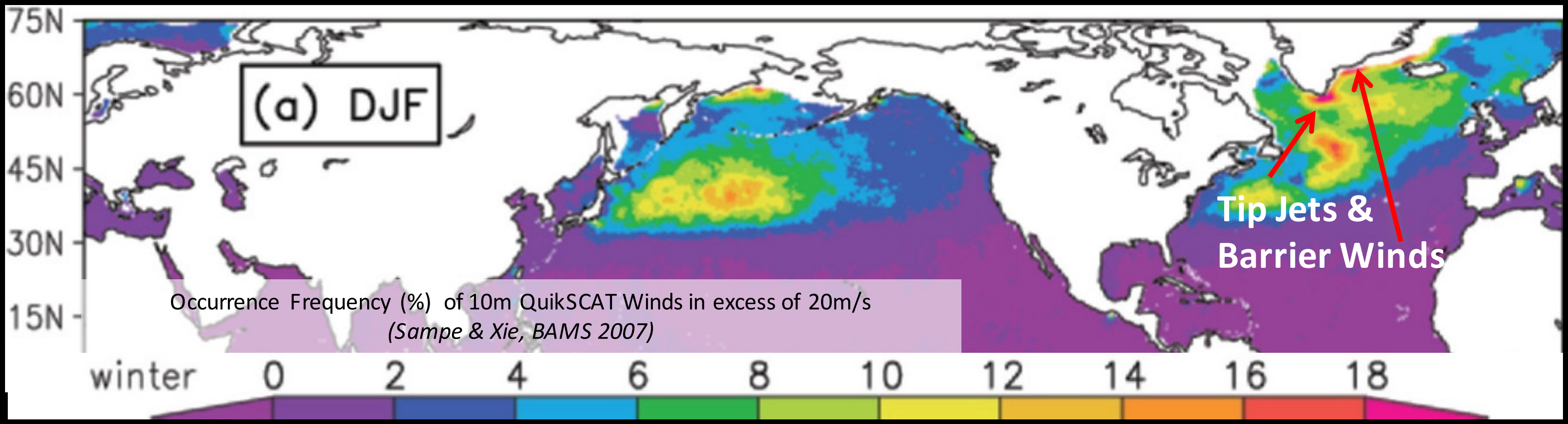
Greenland's Place in Arctic/Global System



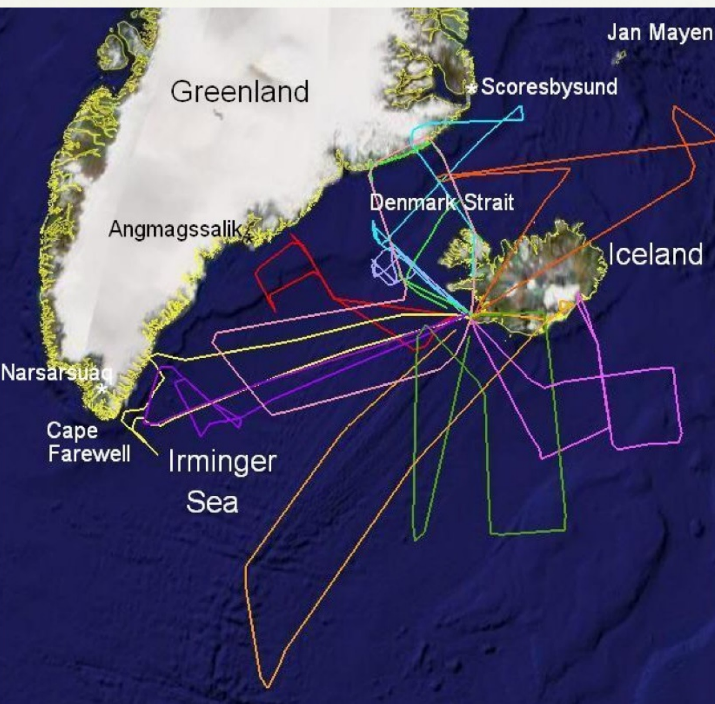
Tracks of 100 most intense winter extra-tropical cyclones 1989-2008 (Courtesy U. of Reading)

- High complex topography
- Proximity to North Atlantic storm track
- Yield topographically forced weather systems (*tip jets, barrier winds & katabatic flow*)
- Roles in local weather/global climate (sea ice transport, polynyas, ocean circulation)

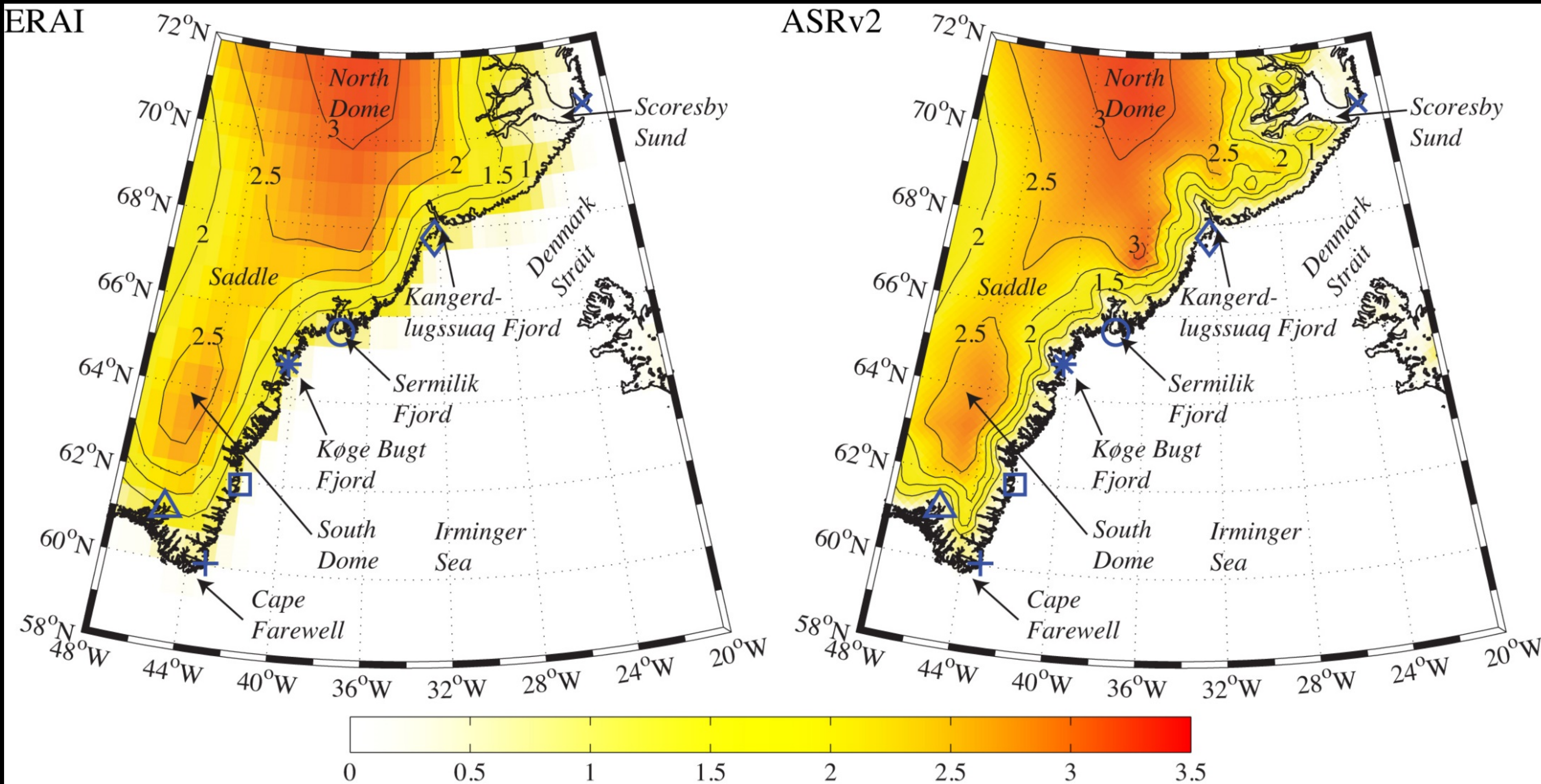


Occurrence Frequency (%) of 10m QuikSCAT Winds in excess of 20m/s
(Sampe & Xie, BAMS 2007)

GFDex airborne campaign (Feb-Mar 07)



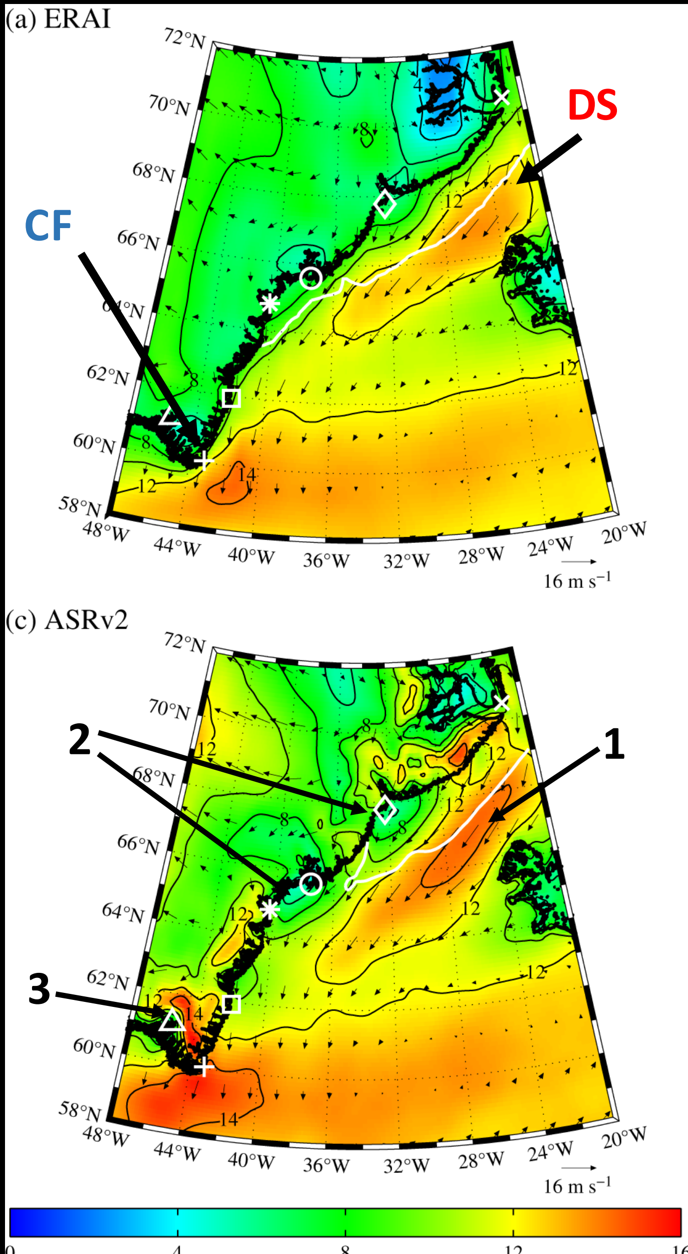
Greenland Topography



Topography of Southern Greenland (km) as represented in the ERA-I (80km) and ASRv2 (15km)

DMI stations in the region are indicated

Barrier Flow



Mean 10 m Wind

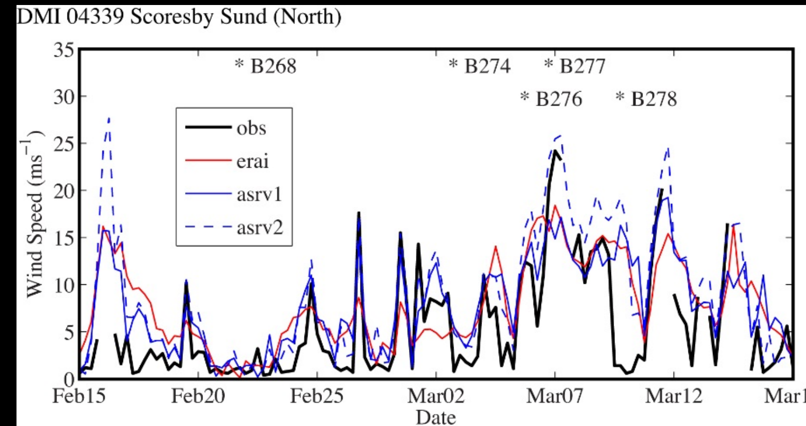
- Both capture enhanced barrier flow along Denmark Strait (DS) and NE flow near Cape Farewell (CF)

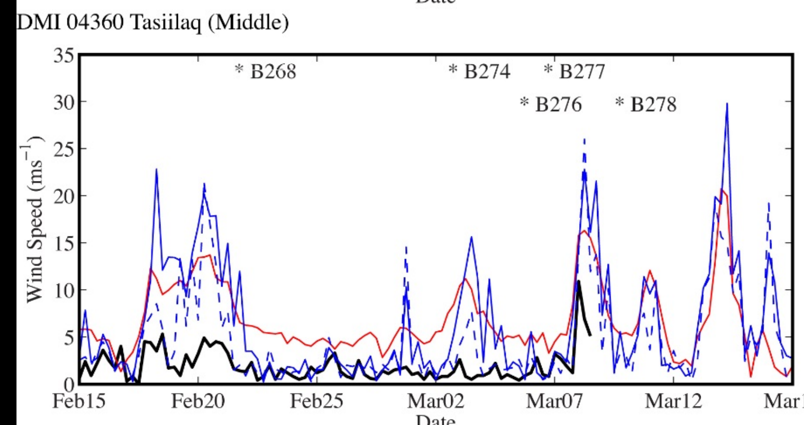
- Increased resolution ≈ higher wind speed

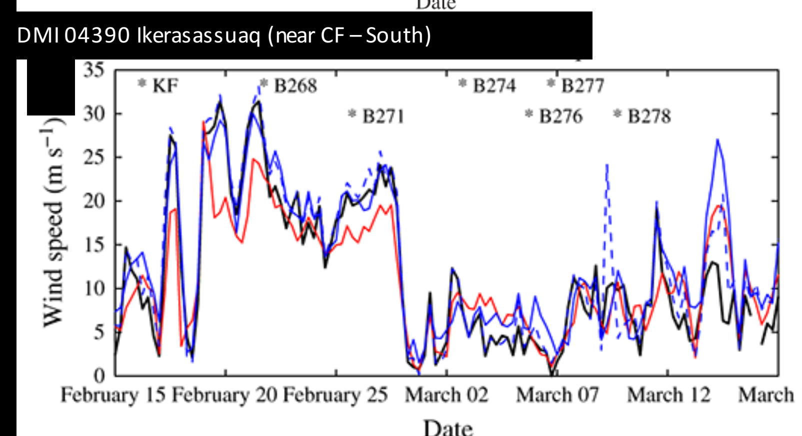
- ASR demonstrates
  1. Enhanced wind speed gradient along ice edge
  2. Low wind speeds downwind of Sermilik and Kangerdlugssuaq Fjords (topographic sheltering effect Moore et al. GRL 2015)
  3. Onshore extension of high wind speed near CF

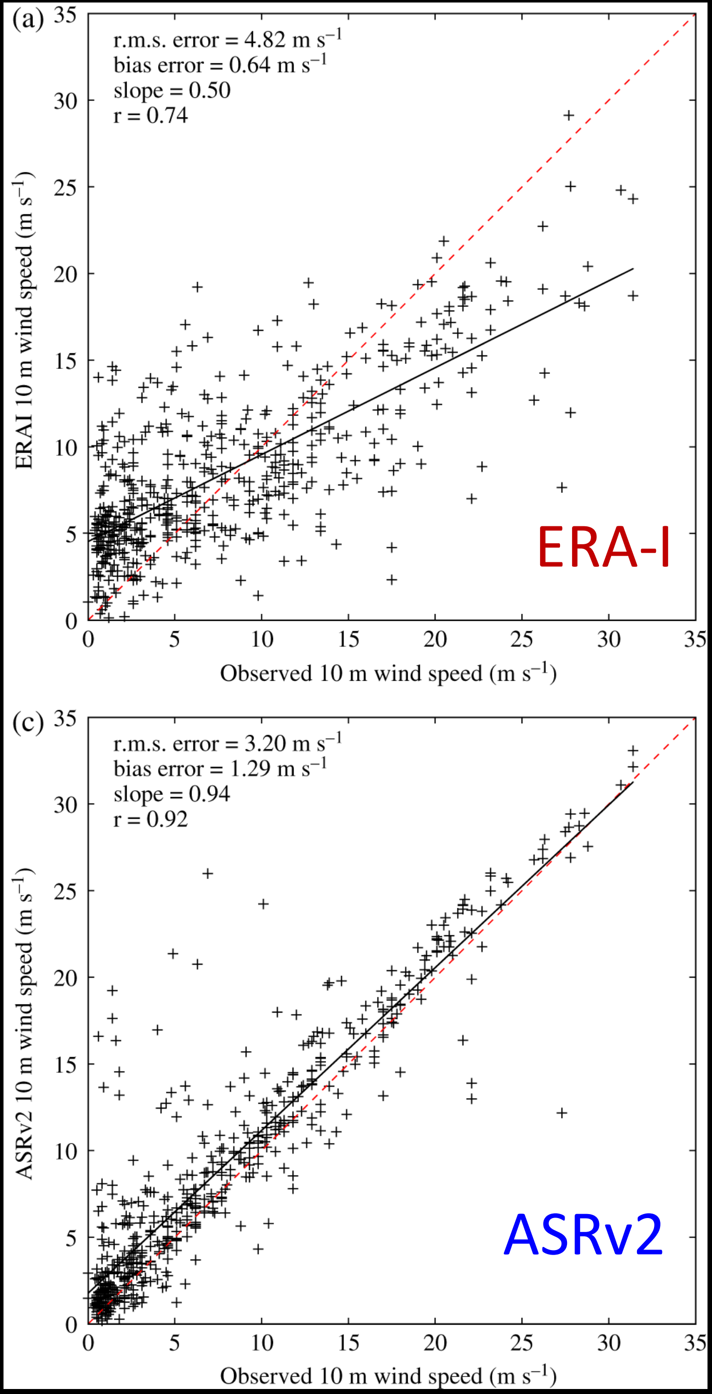
10 m Wind Speeds at DMI Sites

- Winds generally stronger in the southern sites during first half
- B268 flight investigated Easterly Tip Jet near Ikerasassuaq (CF); ERAI winds too low – better captured by ASR
- Stronger winds in North during second half
- B274, B276, B277, and B278 captured Barrier Wind Event
- Observed winds at Tasillaq lower than reanalyses (sheltering)





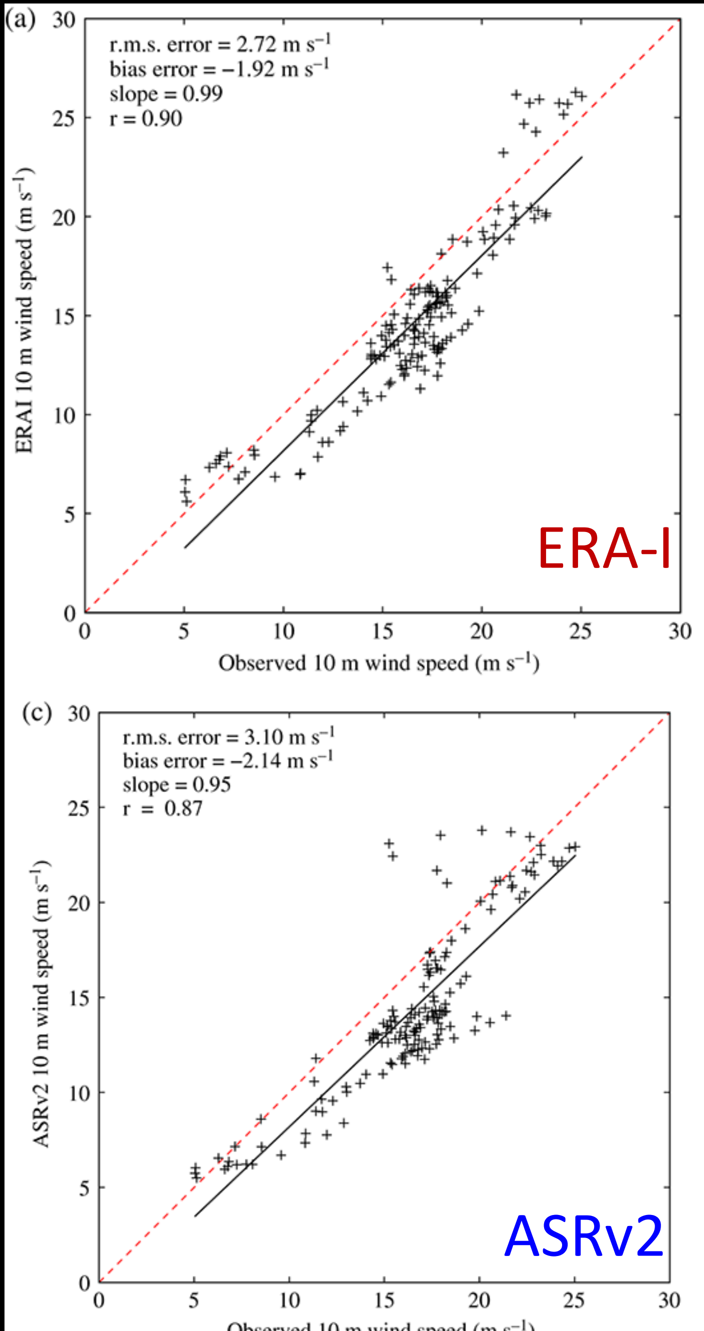




Scatter Plots of the DMI Stations

- ERAI has high/low wind speed bias that is reduced in the ASRv2.
- Both regression slope and correlation coefficient approach 1 as one transitions from the ERAI to ASRv2.
- ASRv2 still overestimates wind speeds during weak wind regimes – likely tied to the sheltering situations

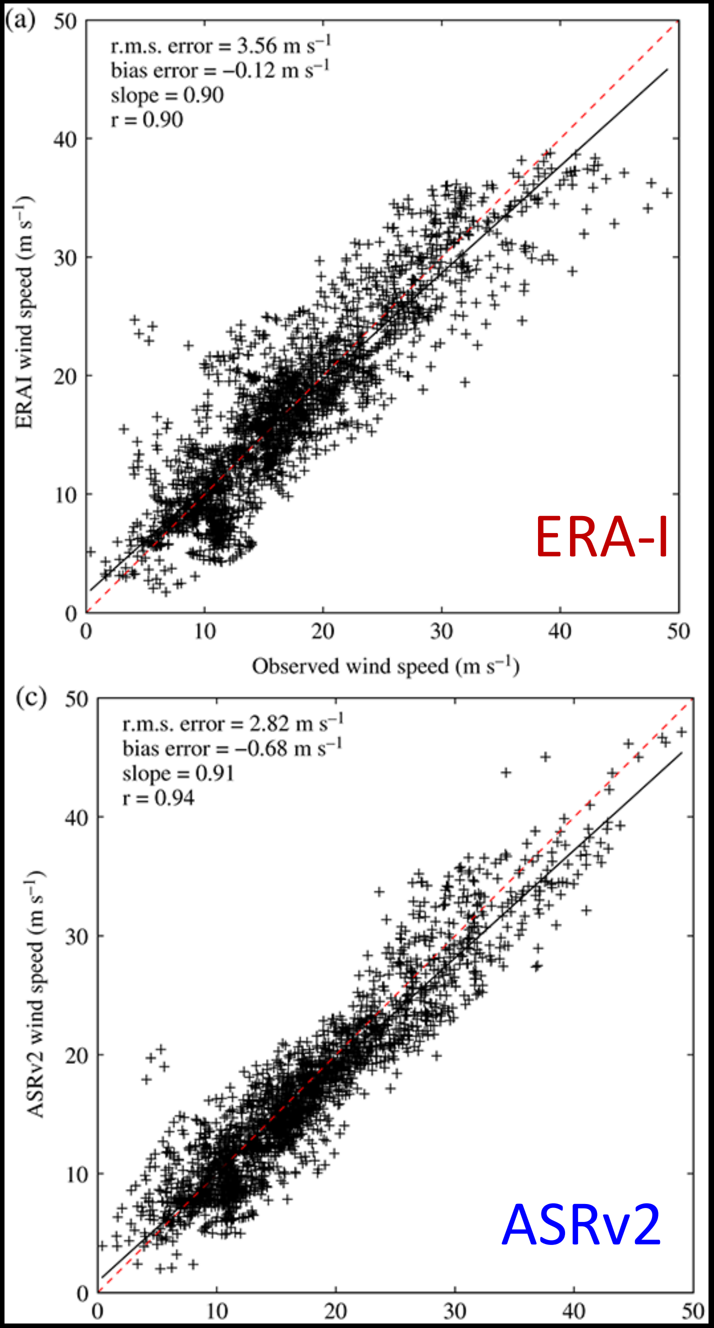
Scatter Plots of the GFDex Low-Level Flight Legs



- Both reanalyses have a systematic low wind speed bias
- No significant difference between the ERAI and ASRv2
- There is a reduction in RMSE and increase in correlation between ASRv1 and ASRv2: perhaps better spatial gradients

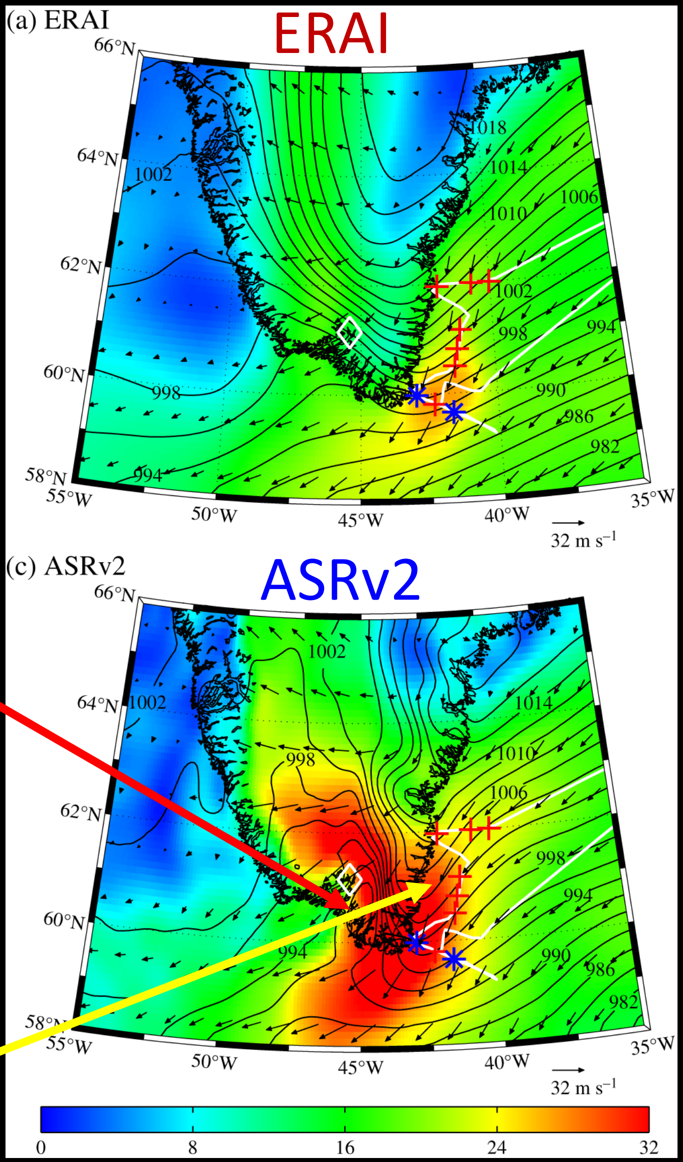
Scatter Plots of the GFDex Dropsondes

- Both reanalyses are similar with respect to the winds from the GFDex dropsondes
- The ASRv2 does a better job with the high winds (> 40 m s^{-1}) but these are not numerous enough to influence the statistics.
- Representation of the vertical structure of off shore jets is marginally improved in the ASRv2
- Resolution may play a bigger role near shore



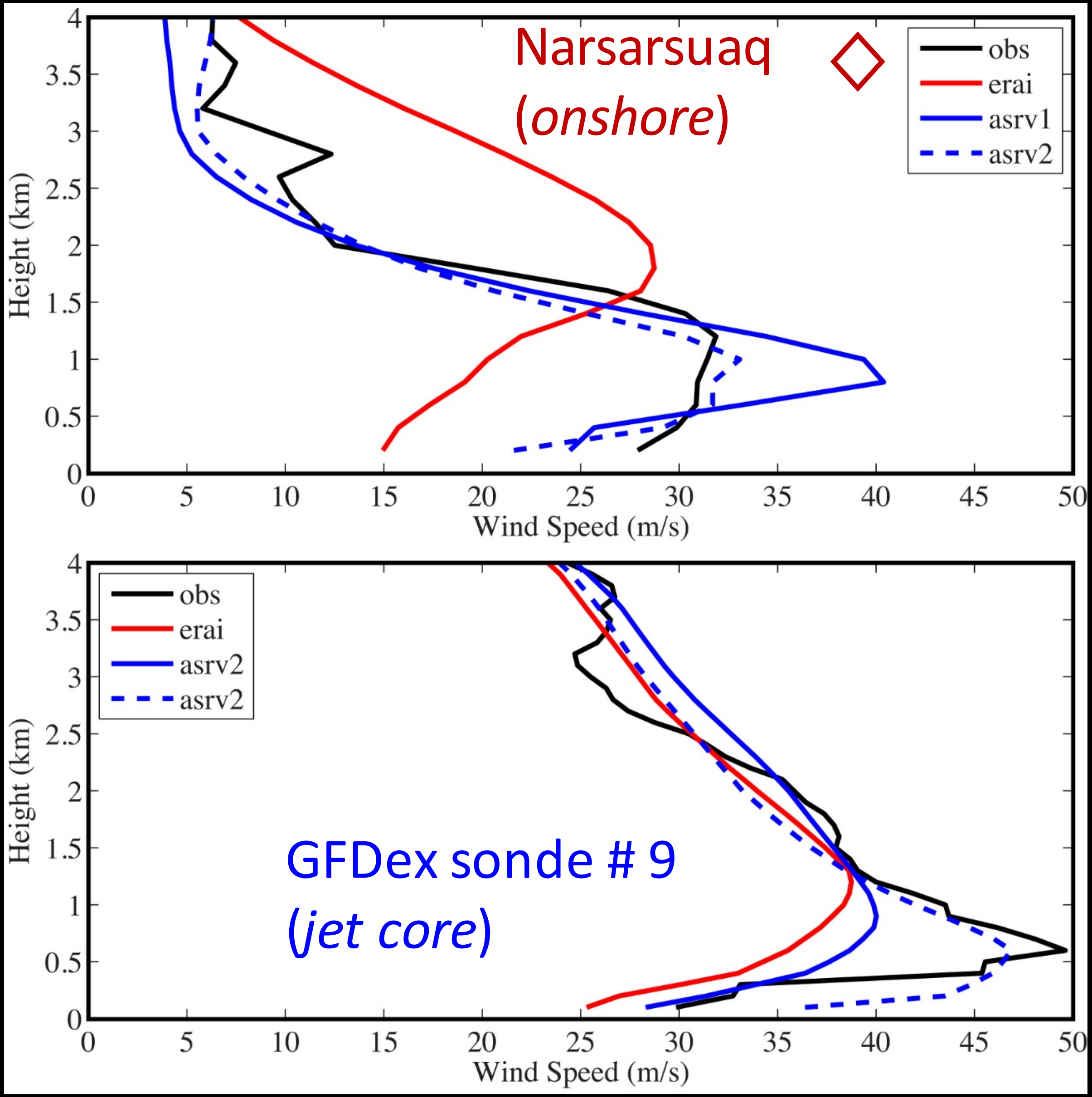
Easterly Tip Jet

- Synoptic Low SE of CF, region under NE flow, broad scale captured well in reanalyses.
- ASRv2 captures the mesoscale low that forms on the lee side of the barrier as well as generally having higher wind speeds.
- ASRv2 also identifies a new feature of ETJ, onshore extension of the flow that may play a role in erosion and aerosol dispersion.



Sea-level pressure (mb-contours), 10m wind (m/s-vectors) and 10m wind speed (m/s-shading) for the easterly tip jet (ETJ) flight (B268- flight track in white with dropsondes indicated) at 12 UTC on February 21 2007

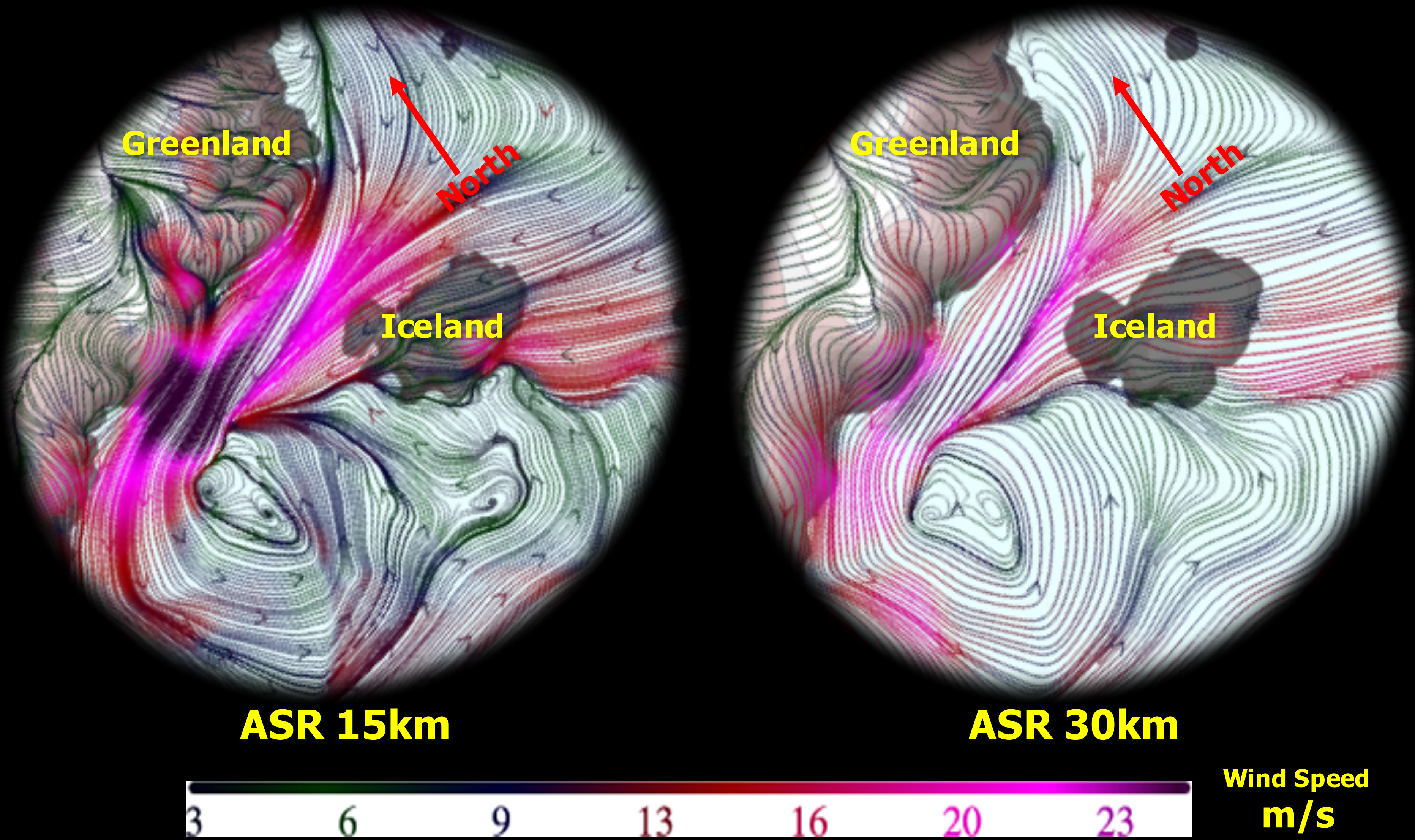
Vertical Structure of the ETJ



Observed and model wind speed profiles during GFDex flight B268

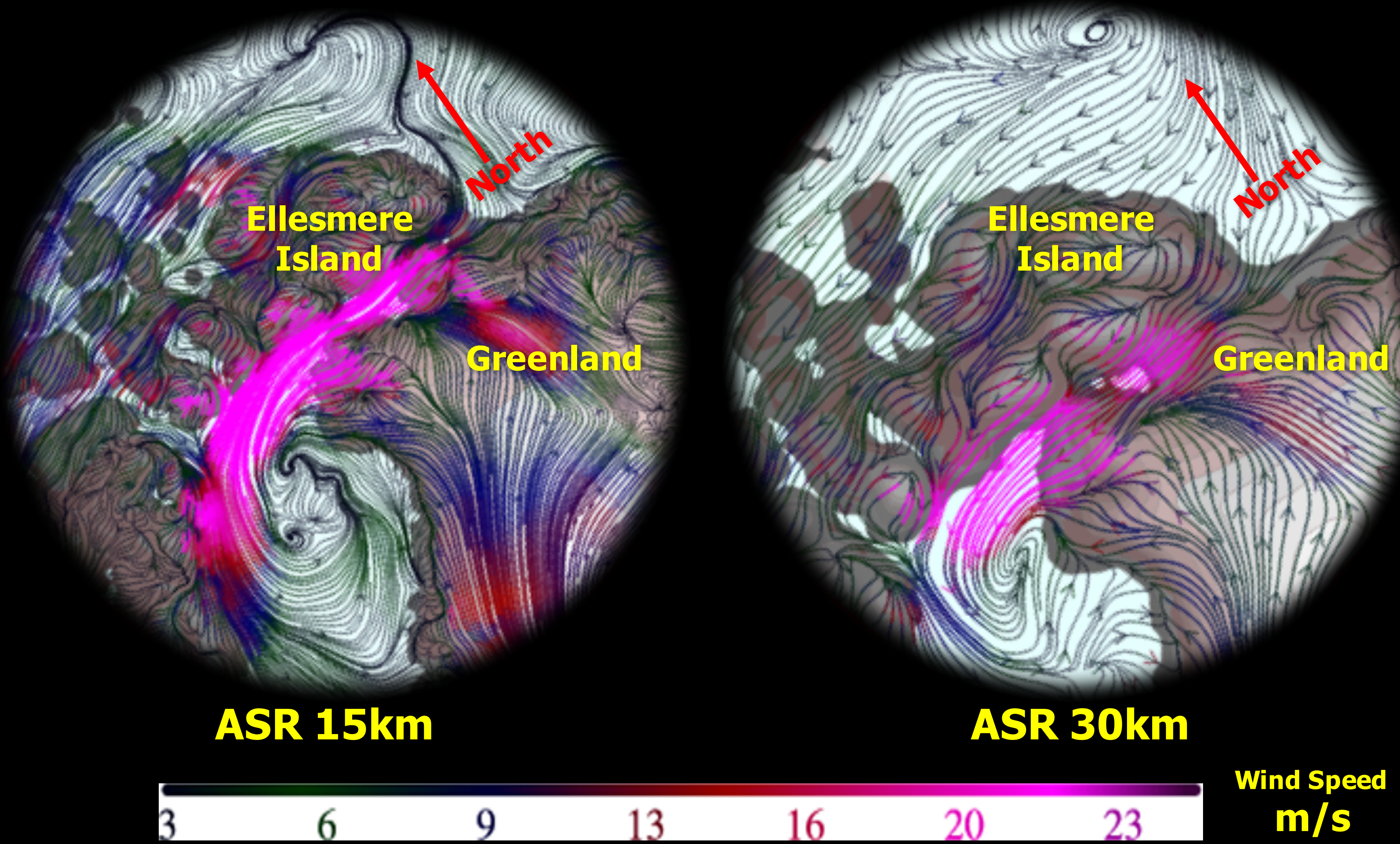
- ERAI missing onshore extension of tip jet
- ASRv2 is able to better represent the onshore and offshore vertical structure of the observed easterly tip jet.

Intense Barrier Wind in Denmark Strait @ 15 km



03UTC Mar 03, 2007

Intense Gap Wind in Nares Strait @ 15 km



03UTC Feb 09, 2007

Summary of ASRv2

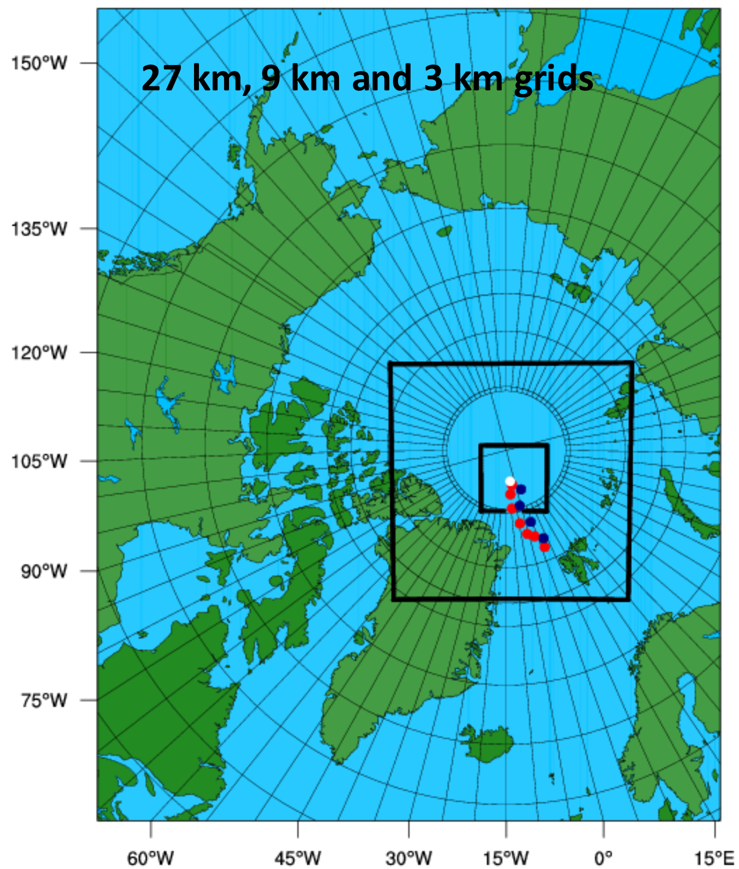
- ASRv2 (15 km; 2000-2012) completed; Now available at NCAR CISL!
- ASRv2 will be brought up to date in the near future
- Surface variables compare very well with surface observations
    - Marked improvement in skill over ERAI in near-surface temperature, moisture, and especially wind speed
- Precipitation and Radiation in ASRv2 improved over ASRv1 (30 km)
    - Decreased excessive summertime precipitation
    - ASRv2 is qualitatively similar to ERAI
    - Positive SW and Negative LW biases are smaller
- Topographically-forced wind events near Greenland resolved well

Next Step: ASRv3

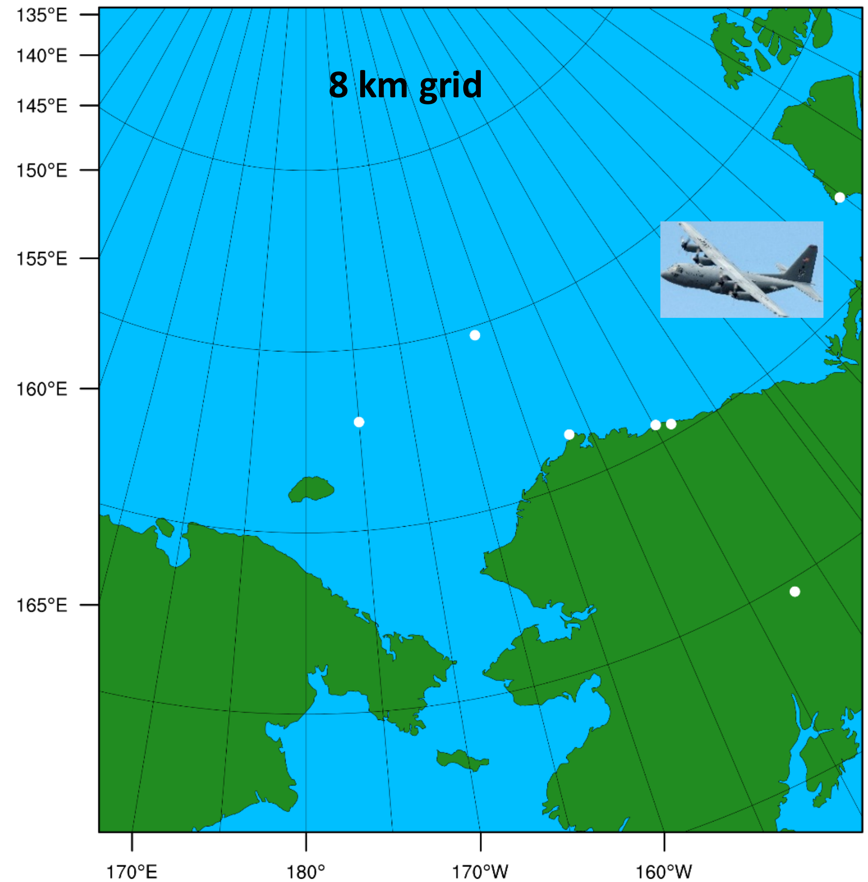
- **Expand the period to 1979-2020**
  - **Spans YOPP and MOSAIC**
- **Upgrades include**
  - **Improved parameterization:** **Better Arctic cloud representation, improved radiation, and aerosols**
  - **Sophisticated Land Surface model:** **Improve snow cover, vegetation, and land-ocean-atmosphere interaction**
  - **Advanced data assimilation:** **Atmosphere, sea ice, land surface, and Greenland Ice Sheet.**
- **Key Intellectual Merit**
  - **Detailed investigations of Pan-Arctic extreme weather and climate**
- **Proposal in review with NSF**

Arctic Cloud Work – Improvements to Polar WRF

ASCOS August 2008



ARISE September 2014



New Polar WRF simulations to study the model representation of Arctic low-level clouds

Hines and Bromwich, 2017: *Mon. Wea. Rev.*

GREATLY REDUCING the Arctic Cloud Condensation Nuclei (CCN) in PWRF CORRECTS the excessive simulated liquid water content in low clouds.

ASCOS has detailed aerosol observations

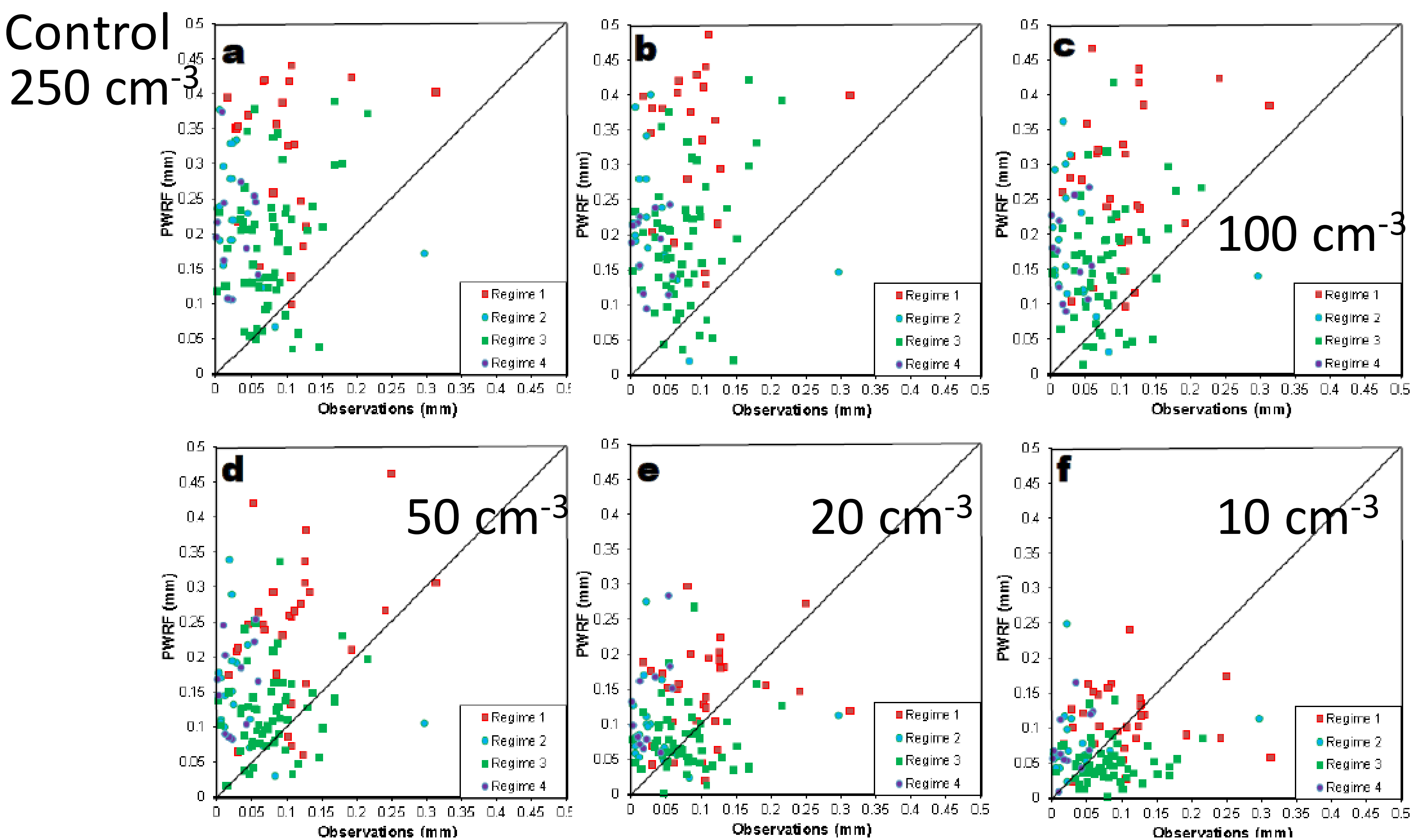


Figure 15. Scatter plots of simulated versus hourly cloud liquid water (mm) for (a) Control, (b) Snow Albedo, (c) Morrison 100 cm^{-3}, (d) Morrison 50 cm^{-3}, (e) Morrison 20 cm^{-3}, and (f) Morrison 10 cm^{-3} at ASCOS during 10 August – 3 September 2008.

GREATLY REDUCING the Arctic Cloud Condensation Nuclei (CCN) in PWRF LEADS to accurate simulations of incident shortwave radiation at the surface

ASCOS has detailed aerosol observations

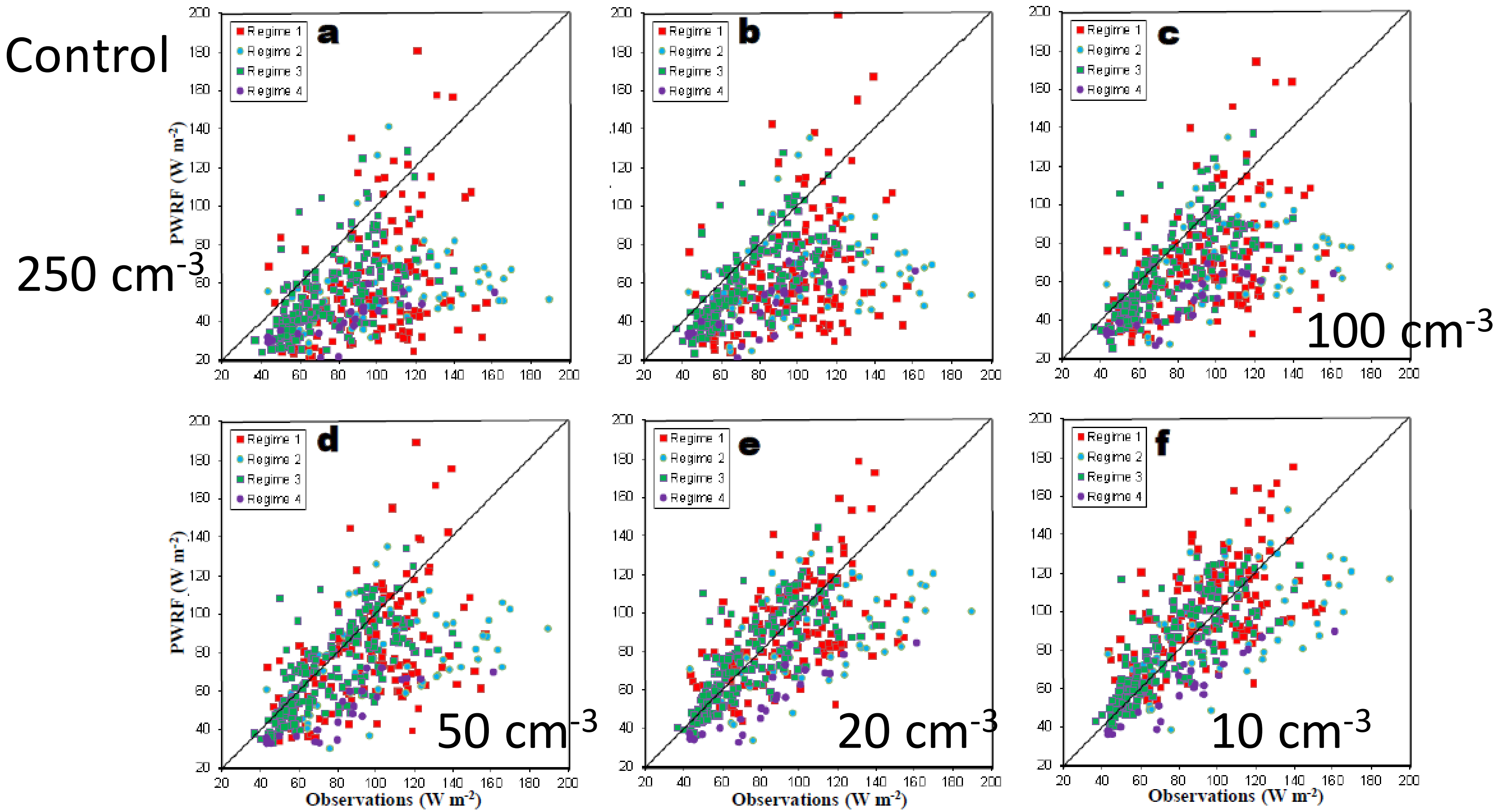


Figure 13. Scatter plots of simulated versus observed hourly incident shortwave radiation (W m^{-2}) for (a) Control, (b) Snow Albedo, (c) Morrison 100 cm^{-3}, (d) Morrison 50 cm^{-3}, (e) Morrison 20 cm^{-3}, and (f) Morrison 10 cm^{-3} at ASCOS during 15-31 August 2008.

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